Final Technical Report:

(U) Aircraft Downwind Hazard Distance After a Chemical Attack

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Headquarters U.S. Air Force (HQ USAF)/Deputy Director for Counterproliferation (A3SC)

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This report describes the development of a rule for the standoff distance from a chemical warfare contaminated aircraft for the Air Force counter-chemical warfare concept of operations (C-CW CONOPS). The 10-foot rule that was originally developed in the C-CW CONOPS described the precautionary procedures used to safely approach a painted, chemically-contaminated vehicle surface at varied times after the chemical warfare agent (CWA) attack. In order to make the 10-foot rule applicable to areas larger than a vehicle surface area, the 10-foot rule needed to be revised. The revision of the 10-foot rule focused on the impact of approaching chemically contaminated painted metal surfaces that were larger than the original vehicle surface area covered in the 10-foot rule, to include rules for safely approaching the contaminated item at different times after the attack. As part of the 10-foot rule revision process, a range of aircraft in the Air Force inventory were examined to generate the spatial extent and geometry to be used in modeling the downwind hazard areas around the aircraft. Further, a parametric study was conducted that used representative contamination densities and patterns, as well as representative aircraft paint combined with wind speed, relative wind direction, and the Pasquill Stability Category (PSC) over the range of anticipated conditions. The results of the parametric study identified the relative risk associated with operations for one-hour at various times (after the attack) and distances from the simulated contaminated aircraft. This report provides time-phased rules of thumb for operations in proximity to contaminated aircraft (and other large contaminated painted metal surfaces larger than $10m^2$).

15. SUBJECT TERMS
C-CW CONOPS; chemical standoff distance for contaminated aircraft; chemically-contaminated vehicle surface area; 10 foot rule revision; and rules for safely approaching contaminated items after a chemical attack.

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Abstract

This report describes the development of a rule for the standoff distance from a chemical warfare contaminated aircraft for the Air Force counter-chemical warfare concept of operations (C-CW CONOPS). The 10-foot rule that was originally developed in the C-CW CONOPS described the precautionary procedures used to safely approach a painted, chemically-contaminated vehicle surface at varied times after the chemical warfare agent (CWA) attack. In order to make the 10-foot rule applicable to areas larger than a vehicle surface area, the 10-foot rule needed to be revised. The revision of the 10-foot rule focused on the impact of approaching chemically contaminated painted metal surfaces that were larger than the original vehicle surface area covered in the 10-foot rule, to include rules for safely approaching the contaminated item at different times after the attack. As part of the 10-foot rule revision process, a range of aircraft in the Air Force inventory were examined to generate the spatial extent and geometry to be used in modeling the downwind hazard areas around the aircraft. Further, a parametric study was conducted that used representative contamination densities and patterns, as well as representative aircraft paint combined with wind speed, relative wind direction, and the Pasquill Stability Category (PSC) over the range of anticipated conditions. The results of the parametric study identified the relative risk associated with operations for one-hour at various times (after the attack) and distances from the simulated contaminated aircraft. This report provides time-phased rules of thumb for operations in proximity to contaminated aircraft (and other large contaminated painted metal surfaces larger than $10m^2$).

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Acronym List

ACADA	Automatic Chemical Agent Alarm
AFMAN	Air Force Manual
AFRL	Air Force Research Laboratory
AGE	Aerospace Ground Equipment
ATDL	Atmospheric Turbulence and Diffusion Laboratory
BM	Ballistic Missile
CAM	Chemical Agent Monitor
CARC	Chemical Agent Resistant Coating
C-CW CONOPS	Counter-Chemical Warfare Concept of Operations
CEX	Civil Engineer Readiness
CWA	Chemical Warfare Agent
DoD	Department of Defense
DPG	Dugway Proving Ground
ECBC	Edgewood Chemical and Biological Center
FM	Field Manual
ICAM	Improved Chemical Agent Monitor
IPE	Individual Protective Equipment
LFADD	Large Frame Aircraft Decontamination Demonstration
MAJCOM	Major Command
MEG	Military Exposure Guideline
MHE	Materiel Handling Equipment
MOPP	Mission Oriented Protective Posture
NATO	North Atlantic Treaty Organization
NSWCDD	Naval Surface Warfare Center Dahlgren Division
ORM	Operational Risk Management
OSD	Office of the Secretary of Defense
PACAF	Pacific Air Forces
PAM	Pamphlet
PSC	Pasquill Stability Category
SRBM	Short Range Ballistic Missile
TBM	Tactical Ballistic Missile
TG	Technical Guide
UAV	Unmanned Aerial Vehicle
USCHHPM	U.S. Army Center for Health Promotion and Preventive Medicine
WDTC	West Desert Test Center

Executive Summary

The "10-Foot Rule" was established as a part of the United States Air Force (AF) Counter-Chemical Warfare Concept of Operations (C-CW CONOPS) to provide guidance for operations near chemically contaminated surfaces. The 10-foot rule provided guidance for protecting personnel that had to use and/or handle chemically contaminated resources or work in locations with materials that might retain a residual chemical hazard longer than the major terrain surface area on which it was located. The 10-foot rule embodied a safety factor that went beyond the existing Office of Secretary of Defense (OSD) guidance, which allowed removal of individual protective equipment (IPE) when detectors no longer detected a chemical agent vapor hazard.

The guidance established that once reconnaissance surveys were completed, and the Commander directed that Mission Oriented Protective Posture (MOPP) 2 was operationally appropriate, operations that were conducted more than 10 feet downwind of a metal or painted metal vehicle (sized $10m^2$) could be accomplished in MOPP 2 during the first 24 hours after an attack. After the first 24 hours, operations could be accomplished next to the contaminated painted metal surfaces with gloves (either work or other protective gloves). This procedure was adopted as an expedient measure to resolve the uncertainty that was created by the potential increased hazard from painted metal surfaces when compared to ground surfaces, which dominated the area. The typical ground surfaces, (e.g., concrete, grass, asphalt, vegetation, and soil) were used in the generation of the hazard duration estimates for both liquid and vapor contamination, which were included in Air Force Manual (AFMAN) 10-2602, *Nuclear, Biological, Chemical, and Conventional Standards and Operations* dated May 2003. The guidelines for the "10-Foot Rule" and the recommendations below were based on the absence of vapor detection measures and a detailed Environmental Health Assessment. If appropriate levels of detection were available, and the operational timelines facilitated completion of the Environmental Health Assessment, then this assessment should be preferred over the expedient measure.

This report focused on the impact on painted metal surfaces that were larger than the original vehicle surface area used in developing the 10-foot rule. These rules were examined to determine the safe approach differences at varying times after an attack. This report reviewed a range of aircraft in the Air Force inventory in order to generate the spatial extent and geometry to be used in modeling the downwind hazard areas around the aircraft. A parametric study was conducted using representative contamination densities and patterns, and representative aircraft and ground support equipment paint, combined with wind speed, relative wind direction, and PSC over a range of anticipated conditions. The results of this parametric study identified the relative risk associated with operations for one-hour at various times and distances from the simulated contaminated aircraft.

The results recommend the following time-phased rules of thumb be employed for operations in proximity to aircraft (and other large contaminated painted metal surfaces), in a zone that is otherwise considered to be safe for MOPP 2 operations:

- In the first hour after an attack, reducing MOPP 4 based on downwind distance is not recommended.
- In 1 to 3 hours after contamination, operations within 500 feet require use of MOPP 4.
    - MOPP 4 at standoff distances of only 50 foot can be accomplished IF the level of contamination on the aircraft can be determined by review of the M8 detection paper to be at or below 50 mg/m^2.
- Between 3 and 24 hours after contamination, only operations within 50 feet require the use of MOPP 4.
- After 24 hours, operations with previously contaminated metal surfaces should be done with gloves (work or protective).

Introduction

After a chemical warfare attack on an airbase, the liquid from the weapon release will contaminate the terrain, facilities, and equipment. This liquid contamination poses a hazard, both from direct liquid contact with skin or from the evaporated vapor. Procedures have been developed by the Air Force to minimize exposure of critical equipment and personnel from the direct effects of the attack. Further, procedures exist for personnel to resume operations, while also minimizing their risk. Due to the toxicity of chemical agents, minimizing exposure is especially challenging because residual hazard may remain for a considerable period of time. From an operational perspective, the issue is whether the risk of liquid or vapor exposure is worth the risk of creating casualties.

For those chemical agents that desorb from surfaces and evaporate rapidly, the agent is dispersed downwind relatively quickly and normal operations can resume. For those chemical agents that do not vaporize quickly, the potential exposure can last longer. Often, the operational commander does not have the flexibility to avoid areas and equipment indefinitely, yet the commander does not want to put their people at risk of severe injury by returning them to unprotected operations. The burden of current chemical protective equipment and the inefficiencies of currently available decontamination techniques also become factors that affect a commander's options. The purpose of the original "10-foot rule" for equipment was to provide a rule-of-thumb for evaluating the risk of continuing unmasked operations downwind from contaminated equipment. This report is an examination of the hazard levels downwind from current Air Force operational aircraft in order to provide a similar rule for these assets.

Background

The development of the CW CONOPS during the late-1990s identified the need to establish an operational rule for use of protective equipment around previously chemically (liquid) contaminated equipment. The fundamental issue was how far personal protection was needed with an operationally acceptable level of risk when a contaminated equipment item was being used in an uncontaminated area. In 2002, Headquarters Air Force, Directorate of Operations, asked the Air Force Research Laboratory (AFRL) to study the expedient rule established by the Civil Engineer Readiness (CEX) experts serving in the Pacific Air Forces (PACAF) Major Command (MAJCOM). The 10-foot rule stated that after approximately one hour, a contaminated vehicle, equipment, materiel handling equipment/aerospace ground equipment (MHE/AGE), cargo pallets, and munitions, in an otherwise "clean environment," can be approached up to approximately 10-feet for one hour of operations with acceptable risk, without the protective mask. The report that was completed by AFRL identified the level of risk and the 10-foot rule was adopted by the Air Force and institutionalized for use across the Air Force in AFMAN 10-2602.

Methodology

The methodology developed to complete this analysis was based on the methodology used for the original 10-foot rule study conducted by AFRL for ground support equipment. The contamination density of typical ballistic missile (BM) releases was used to establish initial contamination levels. The literature was reviewed for data on the evaporation of Soman (GD), Mustard Agent (HD), and VX from painted aircraft surfaces, and data was identified for use in the study. The geometry of 26 aircraft was used to establish the geometry of the agent release as lines of continuous Gaussian plumes based on the identified agent flux data. The sum of the concentration results from downwind of the aircraft was collected on a one-meter-by-one-meter grid, and then compared against toxicological threshold data with different standoff distances. The results were analyzed to draw conclusions on the risks to personnel operating without personnel protection around the aircraft, both spatially and temporally. The results of this analysis technique were given a limited validation based on the Dugway Proving Ground (DPG) testing in the Large Frame Aircraft Decontamination Demonstration (LFADD) program.

Contamination Density

AFRL has asserted that based on their work with North Atlantic Treaty Organization (NATO) Technical Panel 7, that the consensus proposed for adoption was that five g/m^2 be used as the 95^{th} percentile deposition level from a tactical ballistic missile attack.

The recent draft report providing technical data to support the revision to AFMAN 10-2602 conducted an extensive analytic effort to generate the data to support the duration of hazard, as well as the detectability based on a number of different munitions, agents, and weather conditions[1]. This jointly sponsored and supported study by AFRL and the Headquarters, Air Force Deputy Director for Counterproliferation (AF/A3SC) generated a database of results to support the analysis of these issues. An analysis of the contamination density results from this study are summarized in the following figure, which shows that for all cases, the 95^{th} percentile average and the median area coverage for a three km by one km sized operational area were less than 50 mg/m^2.

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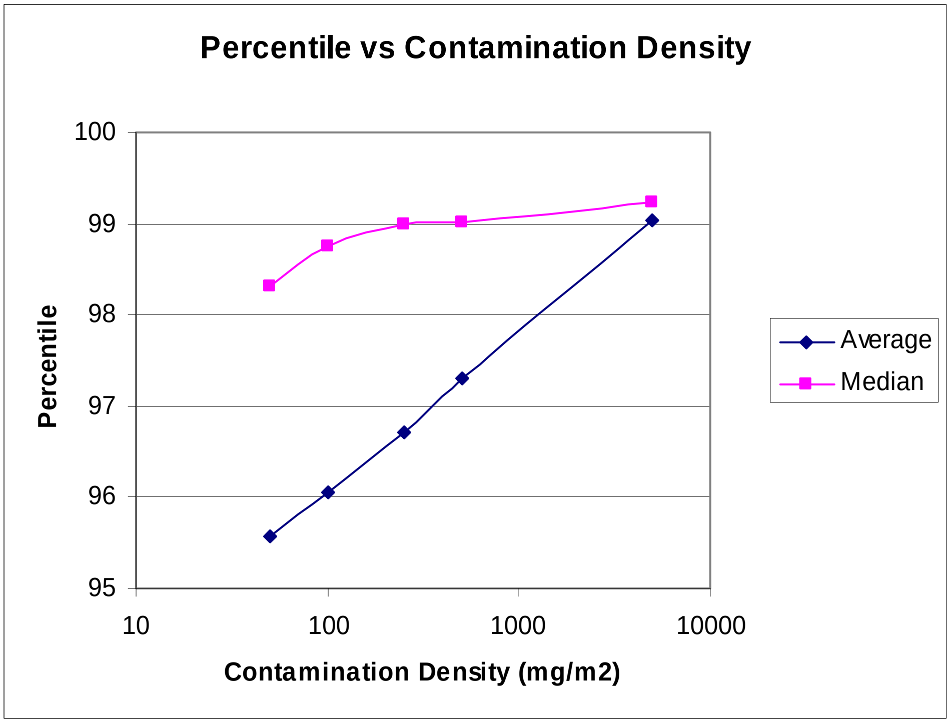

(U) Figure 1: Percentile vs. Contamination Density.

The following table shows the average percent of nominal airbase coverage for the cases with GD, HD, and V-type agents, in both neat and thickened forms. The yellow highlighted cells identify those cases where more than 5% of the one km by three km area was covered by the stated contamination density.

(U) Table 1: Average Percent by Contamination Density and Munition.

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Average Percent by Contamination Density and Munition			
	Contamination Density		
	50 mg/m^2	500 mg/m^2	5,000 mg/m^2
122 Artillery	0.95	0.9	0.7
152 Artillery	0.98	0.92	0.7
Small Rocket	0.97	0.84	0.48
Large Rocket	1.10	0.98	0.69
Cruise Missile	2.12	0.73	0.24
BM Small Sub	6.04	3.85	2.06
BM Large Sub	5.04	3.83	2.03
SRBM-350 Explosive	4.01	3.51	2.15
SRBM-350 Line	8.41	3.13	0.21
BM-500 Explosive	5.15	4.1	2.4
BM-500 Line	9.2	3.79	0.28
Bomb-500	7.91	5.35	0.74

Evaporation Data

There is limited available data that can be used to characterize the evaporation and off-gassing rate of chemical agents from aircraft surfaces. While considerable agent off-gassing and decontamination testing has been conducted on the Chemical Agent Resistant Coating (CARC) used by the Department of Defense (DoD), largely for Army vehicles, there has been only a small number of tests that define the characteristics of the polyurethane paint used widely by the Air Force as the top coat on operational aircraft. Two key references were used to estimate the mass flux from evaporation and off-gassing: Brown (1999) and Davis (2004). Brown looked at the mass flux from aircraft top coat and several other surfaces for thickened Soman (t-GD), thickened Sulfur Mustard (THD), and VX[2]; and Davis studied the results of thickened VX (t-VX and VX) off typical aircraft top coated panels and Advanced Performance Coating (APC) top coated panels[3].

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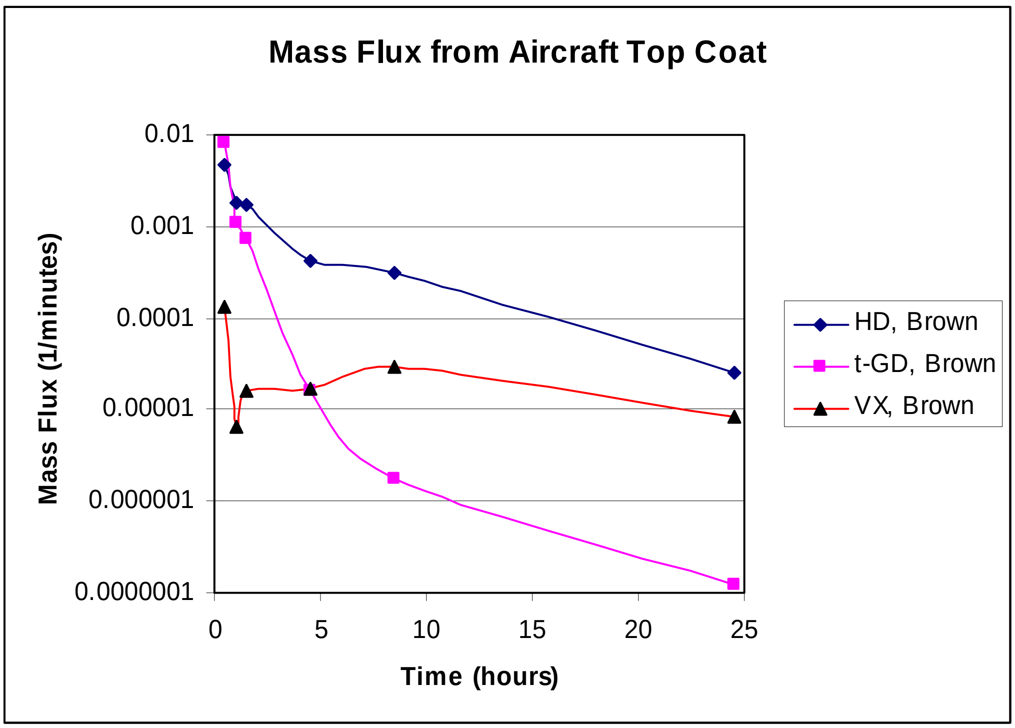

(U) Figure 2: Mass Flux from Aircraft Top Coat.

The cumulative evaporation of t-GD was 34% of the applied agent, 42% of HD, but only 2.3% of VX. The instantaneous evaporation rates of t-GD were low enough that no substantial increases in cumulative evaporation was expected after the last reported time. Further evaporation of HD and VX beyond one day would be expected to affect the cumulative evaporation mass collected.

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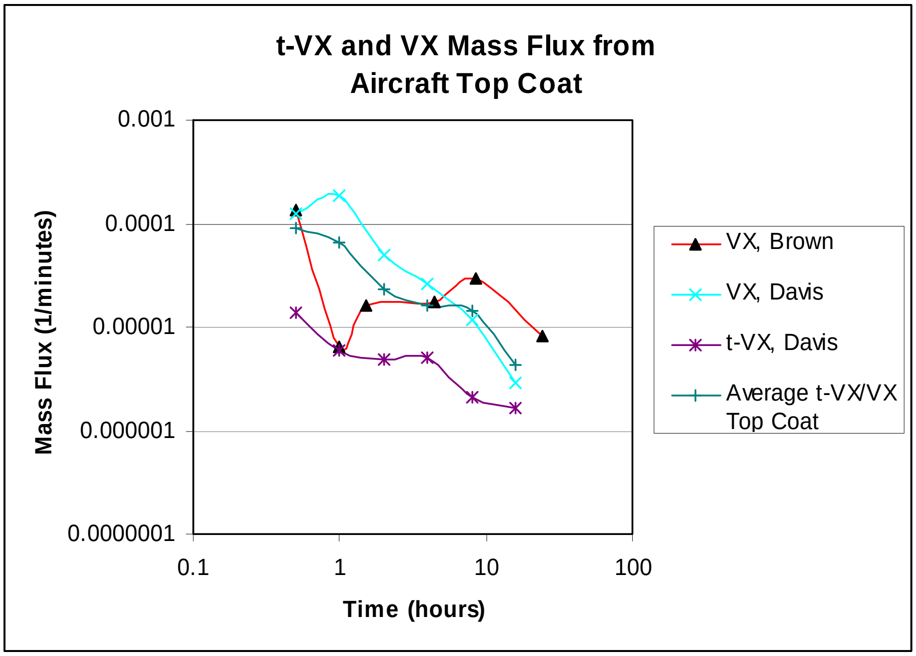

(U) Figure 3: VX Mass Flux from Aircraft Top Coat.

The results from Brown (1999) and Davis (2004) are plotted in the figure above for typical aircraft top coat. The averages of the three data sets were used to generate the VX and thickened-VX results to be calculated for aircraft top coat.

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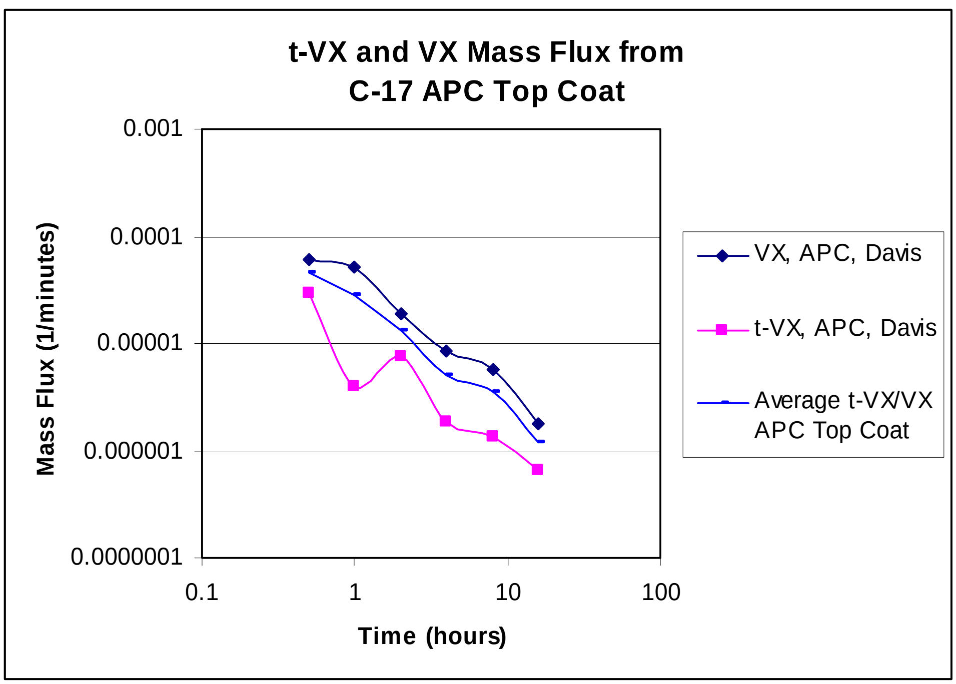

(U) Figure 4: Mass Flux from C-17 APC Top Coat.

The Davis (2004) average results for APC top coat will be used as the mass flux for the C-17. The typical aircraft top coat will be used for the appropriate aircraft results, except for VX on a C-17. While the top coat on some aircraft, (like the F-117, F-22, F-35, Global Hawk, and Predator) may be different in mass flux characteristics, we were not able to obtain any specific test data for those aircraft coatings. The surface area was assumed to be dominated by the aircraft surfaces painted by aircraft top coat, but other materials were known to constitute the remaining surfaces of the aircraft that may also be contaminated, (e.g., canopy, windows, unpainted metal, tires, and a variety of other coatings and sealants). The relative large areas of top coat painted metal is expected to dominate the evaporated agent in the one-hour to 24-hour time domain.

Aircraft Dimensions

The official Department of the Air Force website, www.af.mil, contains a list of operational aircraft and their dimensions, which have been captured in the table below. These dimensions, combined with drawings and pictures of the aircraft, were used to characterize the location, orientation, area, and length of key structural elements of each aircraft.

(U) Table 2: Aircraft Dimensions.

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Aircraft Dimensions				
Aircraft	**Length (feet)**	**Height (feet)**	**Wingspan/ Rotor Diameter (feet)**	**Wing Area (feet^2)**
C-5	247.1	65.1	222.9	
C-17	174	55.08	169.83	
C-20B	83.17	24.5	77.83	
C-20H	88.33	24.5	77.83	
C-21	48.58	12.25	39.5	
C-32	155.25	44.5	124.67	
C-37A	96.42	25.92	93.5	
C-40B/C	110.33	41.17	117.42	
AC-130 H/U	97.75	38.5	132.58	
C-130E/H/J	97.75	38.83	132.58	
C-130J-30	112.75	38.83	132.58	
EC-130E	100.5	38.5	132.58	
EC-130J	97.75	38.8	132.6	
EC-130H	97.75	38.25	132.58	
HC-130P/N	98.75	38.5	132.58	
MC-130E	100.83	38.5	132.58	
MC-130H	99.75	38.5	132.58	
MC-130P	98.75	38.5	132.58	
C-141	168.33	39.25	160.	
A-10/OA-10	53.33	14.67	57.5	
F-15	63.8	18.5	42.8	

F-15E	63.8	18.5	42.8	
F-16	49.42	16	32.67	
F/A-22	62.08	16.67	44.5	
F-35	51.1	17	35	
F-117A	63.8	12.79	42.8	
B-1B	146	34	137	
B-2	69	17	172	
B-52	159.33	40.67	185	
KC-10	181.58	58.08	165.38	
KC-135	136.25	41.67	130.83	
U-2S/TU-2S	63	16	105	1000
E-3	145.87	41.33	130.83	
E-4B	231.33	63.42	195.67	
E-8C	152.92	42.5	145.75	
WC-130	99.33	38.5	132.5	
OC-135B	136.25	41.67	130.83	
RC-135U	136.25	41.67	130.83	
WC-135	139.92	42	130.83	
RC-135V/W	135	42	131	
UH-1N	57.25	12.83	48	
MH-53J/M	88	25	72	
HH-60G	64.67	16.67	53.58	
MQ-1	27	6.9	48.7	
RQ-4	44	15.1	116	
T-1A	48.42	13.92	43.5	
T-6A	33.4	10.7	33.5	
T-37	29.25	9.17	33.67	
T-38	46.33	12.83	25.25	
T-43A	100	37	93	

The next step in the analytical process was to take the aircraft dimensions and develop the lines to represent the source of the Gaussian plume sources to generate the downwind hazard areas. Nominally, eight lines were generated based on the dimensions of the aircraft to represent the right fuselage (mid-height); the left fuselage (mid-height); the top fuselage (centerline); the right wing top (mid-line); the left wing top (mid-line); the horizontal stabilizer (mid-line); the right vertical stabilizer (mid-line); and the left vertical stabilizer (mid-line). All tail configurations were represented.

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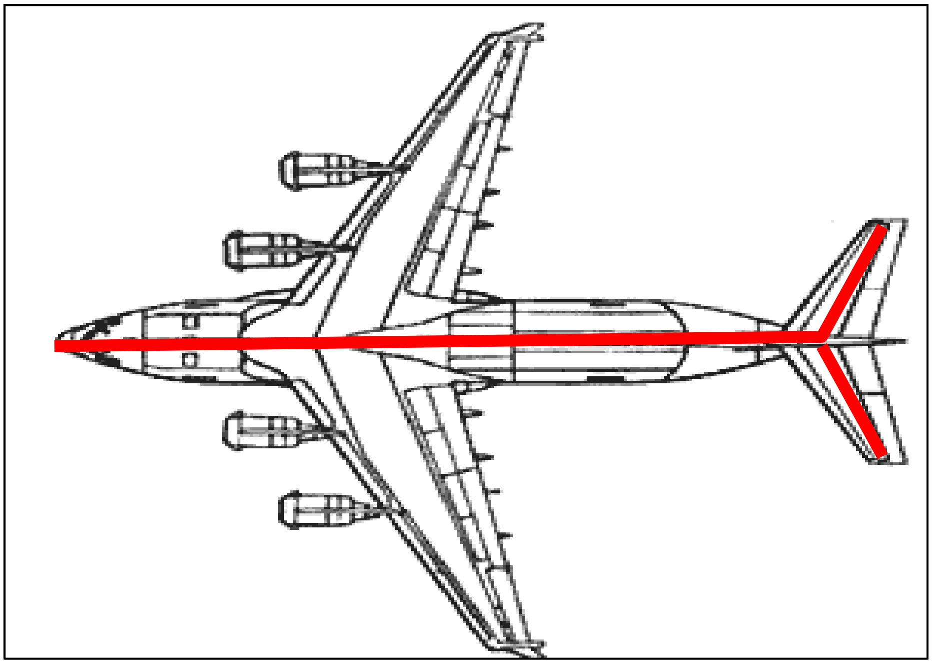

(U) Figure 5: Stylized Top View of Aircraft and Source Lines.

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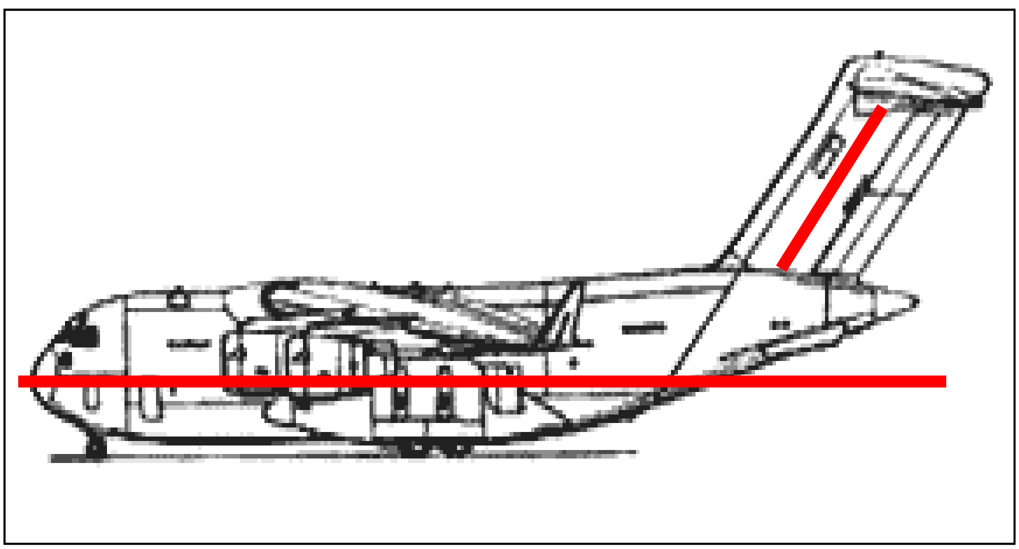

(U) Figure 6: Stylized Left Side View of Aircraft and Source Lines.

Dispersion Characteristics

The representation of sources along lines the length of the major segments of the aircraft allows a plume to be generated every meter along the lines. Hanna (1982) stated on page 25 that, "The Gaussian model is discussed first because it is still the basic workhorse for dispersion calculations and is the one most commonly used because:

1. It produces results that agree with experimental data as well as any model.
2. It is fairly easy to perform mathematical operations on the equation.
3. It is appealing conceptually.
4. It is consistent with the random nature of turbulence.
5. It is a solution to the Fickian[a] diffusion equation for constant K and u.
6. Other so-called theoretical formulas contain large amounts of empiricism in the final stages.
7. As a result of the above, it has found its way into most government guidebooks. Thus acquiring a "blessed" status (Environmental Protection Agency, 1978)[4]."

The Gaussian plume model, which forms the basis for most applied models, was used to illustrate these principles. The model was called "Gaussian" because the cross-wind distributions of concentration were assumed to have a Gaussian (or normal) shape, (.i.e., the Gaussian shape function, $\exp[-y^2/2\sigma_y^2]$ was used).

For a continuous non-buoyant plume with emission rate, Q (mg/s), released at height, h_{rel} (m), above ground, the ground –level concentration, C (mg/m^3), predicted by the Gaussian plume formula was:

$$\boxed{C=(Q/u\pi\sigma_y\sigma_z)\exp(-y^2/2\sigma_z^2)\exp((h_{ref}-h_{rel})^2/2\sigma_z^2)}$$

Where Q was the release rate (mg/sec), u (m/sec) was the wind speed at the release height h_{rel} (m), π was the constant 3.1419, and the reference height, h_{ref} (m) was the height at which concentration was measured, and y (m) was the cross-wind distance from the plume centerline. It was assumed that the trajectories of plumes followed a straight line downwind and that the conditions (wind speed, wind direction, and stability) were constant over the full path of the plume. Concentration distributions at the reference height can be calculated downwind, x (m) and cross-wind, y (m) from the plume using the dispersion coefficients, lateral $\sigma_y(x)$ (m) and vertical $\sigma_z(x)$ (m), based on the table below.

[a] Fick's laws of diffusion describe diffusion and define the diffusion coefficient *D*.

(U) Table 3: Formulas for Lateral and Vertical Dispersion Coefficients.

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Formulas for Lateral and Vertical Dispersion Coefficients, $\sigma_y(x)$ and $\sigma_z(x)$ as a Function of Downwind Distance, x (m)		
Pasquill Stability Class	$\sigma_y(x)$ (m)	$\sigma_{z(}(x)$ (m)
Rural		
A	$0.22x\ (1 + 0.0001x)^{-1/2}$	$0.20x$
B	$0.16x\ (1 + 0.0001x)^{-1/2}$	$0.12x$
C	$0.11x\ (1 + 0.0001x)^{-1/2}$	$0.08x\ (1 + 0.0002x)^{-1/2}$
D	$0.08x\ (1 + 0.0001)^{-1/2}$	$0.06x\ (1 + 0.0015x)^{-1/2}$
E	$0.06x\ (1 + 0.0001x)^{-1/2}$	$0.03x\ (1 + 0.0003x)^{-1}$
F	$0.04x\ (1 + 0.0001x)^{-1/2}$	$0.016x\ (1 + 0.0003x)^{-1}$
Urban		
A-B	$0.32x\ (1 + 0.0004x)^{-1/2}$	$0.24x\ (1 + 0.001x)^{1/2}$
C	$0.22x\ (1 + 0.0004x)^{-1/2}$	$0.20x$
D	$0.16x\ (1 + 0.0004x)^{-1/2}$	$0.14x\ (1 + 0.0003x)^{-1/2}$
E-F	$0.11x\ (1 + 0.0004x)^{-1/2}$	$0.08x\ (1 + 0.0015x)^{-1/2}$
Reference: G.A. Briggs (1973) [5].		

The Briggs dispersion coefficients were used to predict the crosswind and vertical growth of the plume for each source released in the aircraft model. The PSC uses the wind speed, insolation, and cloud cover to type the turbulence expected in a 10-minute sampling period as expressed by Gifford (1976)[6].

(U) Table 4: Meteorological Conditions Defining Pasquill turbulence Types.

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Meteorological Conditions Defining Pasquill Turbulence Types					
A: Extremely unstable conditions			D: Neutral conditions [a]		
B: Moderately unstable conditions			E: Slightly stable conditions		
C: Slightly unstable conditions			F: Moderately stable conditions		
Surface wind speed, m/sec	Daytime insolation			Nighttime Conditions [b]	
	Strong	Moderate	Slight	Thin overcast or > 4/5 low clouds	≤ 3/5 cloudiness
< 2	A	A-B	B		
2-3	A-B	B	C	E	F
3-4	B	B-C	C	D	E
4-6	C	C-D	D	D	D
> 6	C	D	D	D	D
Reference: Gifford (1976) [7].					
[a] Applicable to heavy overcast day or night. [b] The degree of cloudiness is defined as the fraction of the sky above the local apparent horizon that is covered by clouds.					

Cramer (1957) observed the turbulence classes in the table below[8]. In this case, the horizontal turbulence component, σ_θ, and the vertical turbulence component, σ_e, were tied to the stability category. The nature of the random elements of turbulence was a key contributor to the broad applicability of the Gaussian approach. The observation that the standard deviation was achieved within a few meters and was measured at the same time or within a few seconds at the same place was fundamental.

(U) Table 5: Cramer's Turbulence Classes.

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Cramer's Turbulence Classes		
Stability Description	σ_θ, degree (at 10 meters)	σ_e, degree (at 10 meters)
Extremely unstable	30	10
Near neutral (rough surface: trees, buildings)	15	6
Near neutral (very smooth grass)	6	2
Extremely stable	3	1
Reference: Cramer (1957)[9].		

Gifford (1976) related the horizontal turbulent element to PSC in the table below[10].

(U) Table 6: Relationship Among Turbulent Typing Methods.

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Relationship Among Turbulent Typing Methods			
Stability Description	Pasquill	Turner	σ_θ, degree (at 10 meters)
Very unstable	A	1	25
Moderately unstable	B	2	20
Slightly unstable	C	3	15
Neutral	D	4	10
Slightly stable	E	5	5
Moderately stable	F	6	2.5
Reference: Gifford (1976)[11].			

Note that the impact of changes in effective wind direction that typically happen in a diurnal cycle between day, night, dawn, and dusk, or from synoptic weather conditions were NOT represented in the Gaussian approach. While not usually a factor in short term estimates (about an hour as used in this methodology), any extension of the results to longer periods would have to consider this impact.

The Gaussian approach allowed the random meandering of the evolving plume to be evaluated based on the use of dispersion coefficients. The figure below from Hanna (1982) shows the narrower depiction of a 10-minute averaged plume within a larger footprint depiction of a one-hour averaged plume[12]. With the Gaussian assumption that these variations occurred within a "consistent" direction of the wind, the observation was that the one-minute averaged plume was likely to be both narrower spatially and to have a higher peak concentration level when compared to the one-hour averaged plume. Using the empirically-based dispersion coefficients provided a good data fit for a given averaging time.

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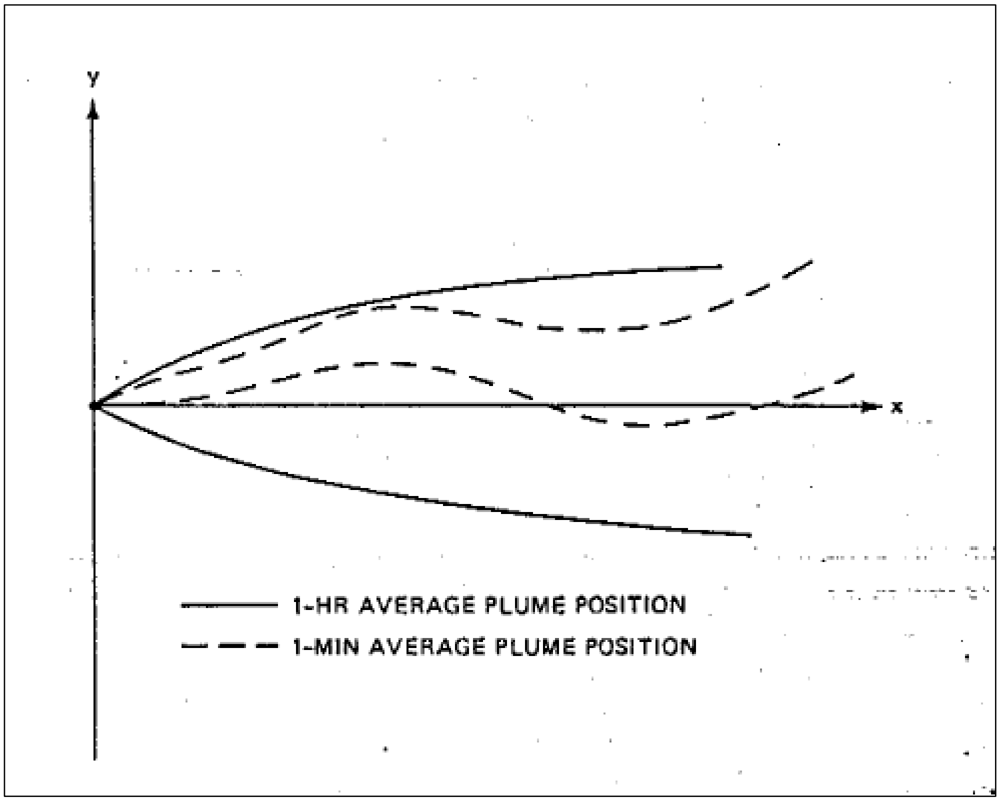


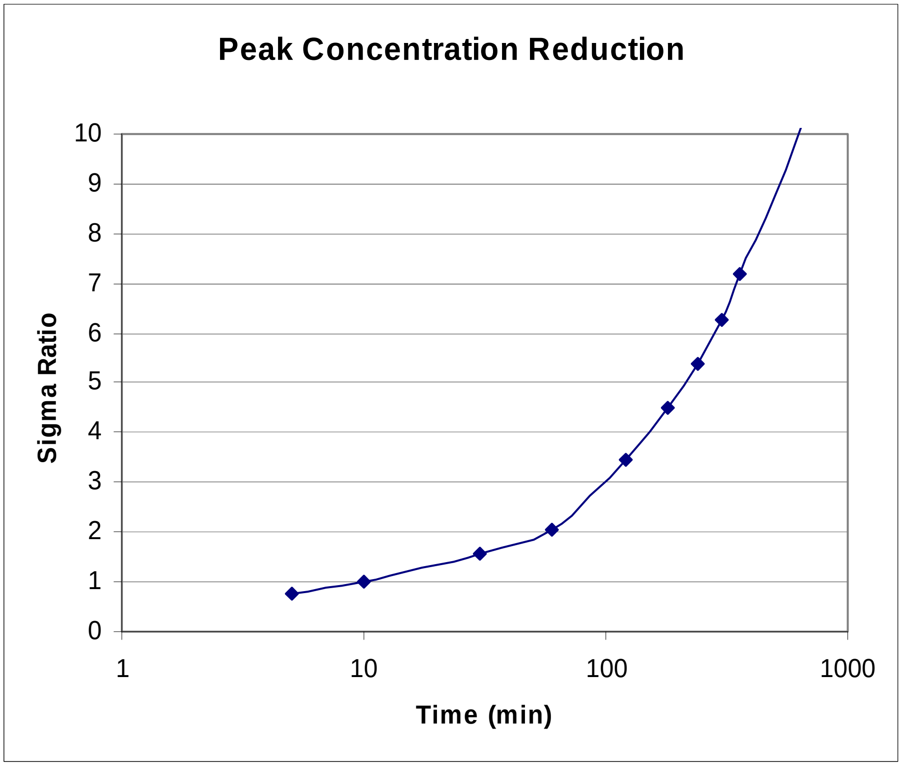
(U) Figure 7: Impact of Time on Average Plume Position.

Gifford (1976) suggested a method of adjusting the sigma to account for changes to the sampling time period.

$$\boldsymbol{\sigma_{yd} / \sigma_{ye} = (T_{sd} / T_{se})^q}$$

σ_{yd}, is the horizontal dispersion coefficient for averaging period d
σ_{ye}, is the vertical dispersion coefficient for averaging period e
T_{sd}, is the averaging period d
T_{se}, is the averaging period e
q, is the exponent:
  0.2 if time of interest is between 3 minutes and 60 minutes.
  0.25 – 0.3 if time of interest is between 1 hour and 100 hours.

The average period for the table above was 10 minutes. The graph below shows that for a one hour averaging sampling time, the net effect on peak concentration (assuming that vertical diffusion coefficient had a similar effect), would be a sigma ratio of two, or a factor of two reduction in peak concentration. <u>THIS FACTOR</u> is not incorporated in the current methodology and reflects an overstatement of expected peak concentrations downwind of the aircraft. Note that a six-hour sampling time would be a reduction in expected peak concentration of nearly a factor of 11.



(U) Figure 8: Peak Concentration Reduction.

Toxicity Thresholds

Four toxicity values were necessary to define the severity of effects and the percentage of the population expected to be effected. The severity of effects were defined by the exposure required to generate a particular level of consequence. For evaluating scenarios, lethality was a critical effect level, as was the level of morbidity, which limited essential task performance (and/or required definitive medical treatment). In the following table, three median levels of severity were used to generate agreed measures of merit.

The three levels of effects were listed in the toxicity tables. The first level, lethality, simply meant death. The lethal effects level was definitive. The median dosage level was often cited as the LCt_{50} value for vapor exposure. The second level of severe effects was a level of injury that would be debilitating for performing a military job and would require definitive medical support. Generally, the severe effects level was at the high end of the exposure spectrum in defining a level of effects that limit performance of critical missions. The median dosage level was often cited as the Severe ICt_{50} value for vapor exposure. The third level of mild effects was a level of injury with noticeable signs and symptoms that may limit performance of some tasks, but generally will require no medical intervention for the levels of exposure to GD, HD, and VX. Generally, the mild effects will only limit performance of tasks with severe workloads (HD) or operation during low-light operations or requiring accurate depth perception (GD and VX). The median dosage level was often cited as the Mild ECt_{50} value for vapor exposure.

Potentially, some mild effects will also limit performance of tasks in bright outdoor conditions for up to several hours for a small fraction of affected personnel (GD, HD, and VX).

In addition to the median response level, two additional parameters were necessary when a toxic load representation was used (GD and HF). The toxic load representation for vapor exposure was used to better match available data, which showed that exposure dosage (concentration multiplied by time) was sensitive to the duration of the exposure. The mathematical formula found to fit the data was k_{alpha} = concentration^n multiplied by time. In other words, the level of exposure necessary to create an effect was a constant of the product of concentration to the n^{th} power times time. The exponent, n, was known as the toxic load exponent. When n = 1, then the exposure dosage was the constant, and it was identical with the traditional values cited as LCt_{50}, Severe ICt_{50}, or Mild ECt_{50} median values. When n > 1 (GD and HD for inhalation exposures), the result was that longer exposure would require higher relative concentrations to create the same level of effects compared to the n = 1 case for exposure times greater than one minute (and less for times less than one minute). To appropriately apply the toxic load relationship, the exposure time associated with the reported median response level must be used to mathematically generate the k_{alpha} value, which was used to assess the casualty expectation.

A fourth toxicity parameter was necessary to characterize the population response to an exposure. A probit relationship was commonly used to represent the fraction of the population responding to a particular exposure. The probit slope was the parameter that generated this relationship, effective exposure = median exposure multiplied by $10^{(Z/PS)}$, where effective exposure was the exposure necessary for a given fraction of the population, median exposure was the exposure causing 50% of the population to have the severity of effect, Z was the standard normal z-score associated with a normal distribution to generate the fraction of the population to be effected, and PS was the probit slope. A probit slope < 1 was associated with a large ratio of exposure necessary to increase exposure from the 16% response up to an 84% response. The higher the probit slope, the smaller the ratio between the 16% and 84% response. For example, GD with a probit slope of 12 would only require < 1.5-fold increase of exposure to go from the 16% and 84% response.

(U) Table 7: Values for Toxicological Modeling.

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Values for Toxicological Modeling										
Agent	**Route**	**Lethal Median**	**PS**	**n**	**Severe Median**	**PS**	**n**	**Mild Median**	**PS**	**n**
GD	Inhalation	35	12	1.5	25	10	1.5	4	6	1.4
HD	Inhalation	1,000	6	1.5	100	3	1	25	3	1
VX	Inhalation	15	6	1	10	.6	1	0.04	4	1
Median values for GD, HD, and VX inhalation were provided as mg-min/m^3 at 15 liters/minute breathing rate. GD, HD, and VX values were extracted from FM 3-11.9 (2005)[13]. VX mild median was extracted from Thomson (2005)[14].										

From these toxicological values, the threshold values to be used in this analysis are tabulated below. The assumption for this analysis was that the exposure would be for one-hour at a 60 liter/minute breathing rate for lethal and severe consequences. Mild effects were assumed to be independent of breathing rate and based on the direct effect to the eye for GD and VX, and the direct effect on the eye and skin for HD. For the one-hour exposure, toxic load calculations were not used because the vapor data provided only an average concentration over the time period, not the instantaneous concentrations as they changed over the one-hour exposure periods that were assumed.

(U) Table 8: Toxicity Threshold Values.

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Toxicity Threshold Values			
	GD	HD	VX
LCt50 [1] (mg-min/m^3)	35	1,000	15
LCt50 [2] (mg-min/m^3)	8.75	250	3.75
LCt16 [2] (mg-min/m^3)	7.22	170.5	2.55
Lethal Threshold [3] (µg/m^3)	120	2,837	42.6
Severe ICt50 [1] (mg-min/m^3)	25	100	10
Severe ICt50 [2] (mg-min/m^3)	6.25	25	2.5
Severe ICt16 [2] (mg-min/m^3)	4.96	11.6	1.7
Severe Threshold [3] (µg/m^3)	82	193	28.4
Mild ECt50 (mg-min/m^3)	0.4	25	0.04
Mild ECt16 (mg-min/m^3)	0.27	11.6	0.022
Mild Threshold [3] (µg/m^3)	4.5	193	0.37

[1] Based on 15 liters/minute breathing rate.
[2] Based on 60 liters/minute breathing rate.
[3] Based on 60 minutes of exposure.

Parametric Analysis

A run matrix for the conduct of this analysis was developed to explore the contributions of several different factors that could affect the results. This resulted in a matrix of 1,942,056 cases.

The 37 aircraft were identified based on the official Air Force Headquarters web site as those aircraft in active service. While the website identified 49 aircraft/models, the various versions of the basic C-130 with the same dimensions were not separately identified for the parametric analysis.

Data for agent evaporation from aircraft painted surfaces was found for three agents: VX (and thickened VX [t-VX]), t-GD, and HD.

The AFRL original 10-foot rule established 5,000 mg/m^2 as an acceptable upper-level contamination density for multiple tactical ballistic missiles (TBM) attacks accepted by NATO Panel 7 as an estimate of the 95th percentile in the mid-1990s. A second level of contamination at 500 mg/m^2 was representative of the LFADD-identified contribution from decontamination (of a 5,000 mg/m^2 contaminated surface), or a level slightly above the average 95^{th} percentile contamination density from TBMs. A third level of 50 mg/m^2 was representative of the AFMAN 10-2602 case matrix of the 95^{th} percentile cases.

Six levels of standoff distance were run; 10, 25, 100, 250, and 500 feet. Nine values for aircraft rotation relative to wind direction were selected to identify the sensitivity to aircraft orientation. The seven angles representing 210 through 330 degrees were not run because they were a symmetrical geometry and would not have represented a different outcome. The six time values represented the available data sources for agent paint evaporation data. The six PSC classes A, B, C, D, E, and F were run and three windspeeds of one, three, and five meters per second (m/s) were run.

(U) Table 9: Parametric Run Matrix.

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Parametric Run Matrix							
Aircraft	**Agent**	**Contamination Density (mg/m^2)**	**Standoff Distance (ft)**	**Aircraft Rotation (deg)**	**Time (hrs)**	**Pasquill Stability Category**	**Wind speed (m/sec)**
C-5	t-GD	5,000	10	0	0.5	A	1
C-17	HD	500	25	30	1	B	3
C-20	VX	50	50	45	2	C	5
C-21			100	60	4	D	
C-32			250	90	8	E	
C-37			500	110	24	F	
C-40				135			
C-130				150			
C-130J130				180			
C-141							
A-10							
F-15							
F-16							
F/A-22							
F-35							
F-117							
B-1							
B-2							
B-52							
KC-10							
KC-135							
U-2							
E-3							
E-4							
E-8							
OC-135							
RC-135							
UH-1							
MH-53							
HH-60							
MQ-1							
RQ-4							
T-1							
T-6							
T-37							
T-38							
T-43							

Operational Risk Methodology (ORM)

Risk is a combination of the severity of the effects and the likelihood of those effects occurring that was captured by these metrics. In this effort, the larger hazard areas represented a higher severity of effects, while the percent of cases with zero area represented the likelihood of those effects. By using an appropriate challenge level (like the 95th percentile worst-case attack conditions), the implications of the risk can be judged.

The following tables reproduce the Risk Assessment Matrix developed in FM 100-14, *Risk Management*[15]. These tables were based on determining the chemical hazard probability category where three primary considerations were used to determine the potential degree of exposure: 1) Comparability of the airfield's exposure profile, (e.g., exposure factors, frequencies, and durations) to the standard exposure profile used in the derivation of the exposure guideline(s) of concern; 2) Proportion of the field unit that is likely to experience exposures relative to the specific exposure guidelines; and 3) Confidence in the available data, given the sources of uncertainty and variability.

FM 100-14 defined the following categories to an identified chemical hazard to indicate the probability of personnel exposures to concentrations equal to or greater than the exposure criteria:

- Frequent – Occurs very often, continuously experienced.
- Likely – Occurs several times.
- Occasional – Occurs sporadically.
- Seldom – Remotely possible; could occur at some time.
- Unlikely – Can assume will not occur; but not impossible.

The recommended approach based on the U.S. Army Technical Guide (TG) 248 to establish Hazard Probability Ranking is as shown in Table 10.

(U) Table 10: Hazard Probability Ranking.

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Hazard Probability Ranking				
Percent of Personnel that will Experience Exposure to Concentrations Equal to or Greater than Exposure Criteria				
< 10%	10 < 25%	25 < 50%	50 < 75%	> 75%
Unlikely	Seldom	Occasional	Likely	Frequent

The ORM risk levels are defined in FM 100-14 (Table 3-3) and were presented with unit status suggestions from FM 101-5-1, *Operational Terms and Graphics*[16] (Table 3-4) to create a risk characterization paradigm that was consistent with operational doctrine developed for the U.S. Army. The concept of unit strength status, (e.g., "below 50% strength") refers to the overall loss of resources that would otherwise be directed towards the planned mission tasks.

(U) Table 11: Risk Assessment Matrix (FM 100-14).

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Risk Estimate					
	Hazard Probability				
Hazard Severity	Frequent (A)	Likely (B)	Occasional (C)	Seldom (D)	Unlikely (E)
Catastrophic (I)	Extremely High	Extremely High	High	High	Moderate
Critical (II)	Extremely High	High	High	Moderate	Low
Marginal (III)	High	Moderate	Moderate	Low	Low
Negligible (IV)	Moderate	Low	Low	Low	Low

The risk levels in the Army regulation were related to either a defined consequence or the unit status as identified below.

(U) Table 12: Risk Level Determination.

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Risk Level Definition		
Risk Level	Defined Consequence (FM 100-14)	Unit Status (FM 101-5-1)
Extremely High	Expected loss of ability to accomplish the mission.	Black (Unit Requires Reconstitution). Unit below 50% strength.
High	Expected significant degradation of mission capabilities in terms of the required mission standard, inability to accomplish all parts of the mission, or inability to complete the mission to standard if hazards occur during the mission.	Red (Combat Ineffective). Units at 50-69% strength.
Moderate	Expected degradation mission capabilities in terms of the required mission standard will have a reduced mission capability if hazards occur during mission.	Amber (Mission Capable, with minor deficiencies). Unit at 70 – 84% strength.
Low	Expected losses have little or no impact on accomplishing the mission.	Green (Mission Capable). Unit at 85% strength or better.
The unit rates provided under Unit Status are to be determined by the commander. Charts similar to the example Hazard Probability and Severity Ranking Charts presented above should be aligned with the acceptable risk levels provided by the commander.		

The hazard severity levels defined by the ORM process have been interpreted by USCHPPM in generating Technical Guide (TG) 230[17]. The Military Exposure Guideline (MEG) values in TG 230 provide a range associated with the ORM categories. The levels selected for use by this study can be associated with ORM hazard severity levels (reference Table 13).

(U) Table 13: Comparison of Toxicity Threshold Values with ORM Hazard Safety Level.

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Comparison of Toxicity Threshold Values with Operational Risk Management (ORM) Hazard Severity Level (ug/m3)				
		GD	HD	VX
Study Toxicity Threshold Levels	Lethal	120	2,837	42.6
	Severe	82	193	28.4
	Mild	4.5	193	0.37
ORM Hazard Severity based on USCHPPM MEG Levels	Catastrophic	> 130	> 2,100	> 3.3
	Critical	> 18 ≤ 130	> 100 ≤ 2,100	> 0.98 ≤ 3.3
	Marginal	> 3.5 < 18	> 67 < 100	> 0.08 ≤ 0.98
	Negligible	< 0.2 ≤ 3.5	> 20 ≤ 67	> 0.009 ≤ 0.08
Corresponding ORM Hazard Severity Level were provided in USCHPPM TG 230 (2002).				

For GD, the lethal and severe thresholds fell into the critical hazard severity range and the mild threshold fell into the marginal hazard severity range. For HD, the lethal threshold fell into the catastrophic hazard severity range and the severe and mild thresholds fell into the critical hazard severity range. For VX, the lethal and severe thresholds fell into the catastrophic hazard severity range and the mild threshold fell into the marginal hazard severity range.

The hazard probability levels in FM 100-14 were associated with the quantitative ranges of the unit that can be affected. In this study, there were two area-based metrics; the area covered in excess of 1,000 m^2, 100 m^2, and 10 m^2 for each toxicity value and the percent of the cases where zero area was above the threshold toxicity value. The largest area metric of 1,000 m^2 was still equivalent to only 0.033% of an airbase. If this was used as the hazard probability, then all cases less than 1,000 m^2, which is for all categories of results and for all toxicity threshold levels, the hazard probability categorization is an "Unlikely" hazard probability, when the entire airbase was considered the target.

For this study, the percent of cases with zero area covered above the toxicity threshold was used as the metric for comparison against the cases in the risk matrix. This resulted in an even more conservative interpretation than any Army unit, and the value thus represented the percent of cases that were above the threshold based on nearly two million total parametric cases.

(U) Table 14: Risk Matrix.

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Risk Matrix						
Toxicity Threshold Levels	GD		HD		VX	
	Seldom 80 or 90% zero area cases	Unlikely 95, 99, or 100% zero area cases	Seldom 80 or 90% zero area cases	Unlikely 95, 99, or 100% zero area cases	Seldom 80 or 90% zero area cases	Unlikely 95, 99, or 100% zero area cases
Lethal	Moderate	Low	High	Moderate	High	Moderate
Severe	Moderate	Low	Moderate	Low	High	Moderate
Mild	Low	Low	Moderate	Low	Low	Low
Risk categories based on FM 100-14 categories and USCHPPM values of Hazard Probability and Hazard Severity.						

Results

The following figures provide a representation of the typical concentration results and show characteristics of the downwind results produced by the model. Downwind from the aircraft, the concentration profile was relatively narrow initially and then gradually spread laterally as the released material diffused downwind, which was quite characteristic of the summation of Gaussian-distributed sources.

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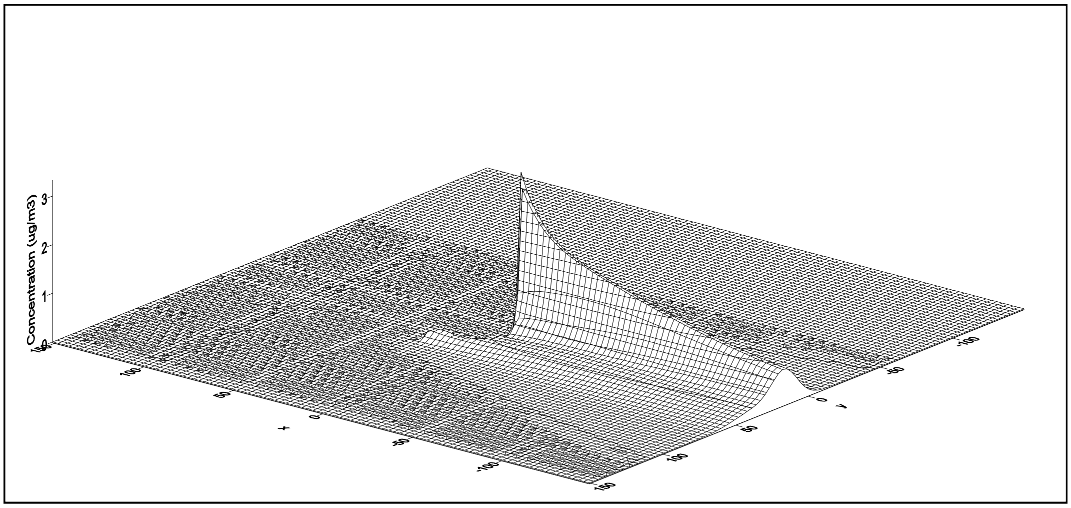

(U) Figure 9: Oblique View of Downwind Concentration Footprint.

Figure 10 shows a top-down view of the same geometry that resulted in the figure above. It is possible to see the 15-degree rotation of the aircraft represented in the resulting pattern laterally and once again, the high number of contours along the centerline, which illustrated a very sharply decreasing concentration level crosswind. These contours illustrated that the area at high risk downwind from the aircraft was very long and narrow with the artificial nature of constant wind direction. In the real world, the variations in wind direction are expected to change over a short period of time (as discussed in the weather section), which would make it very difficult to stay within the downwind hazard for the one-hour duration used to estimate the toxicity-based casualty results. This is a critical point of this analysis. The quantitative results presented below are undoubtedly a systematic overestimate of the likely consequences to anyone operating downwind of the contaminated aircraft.

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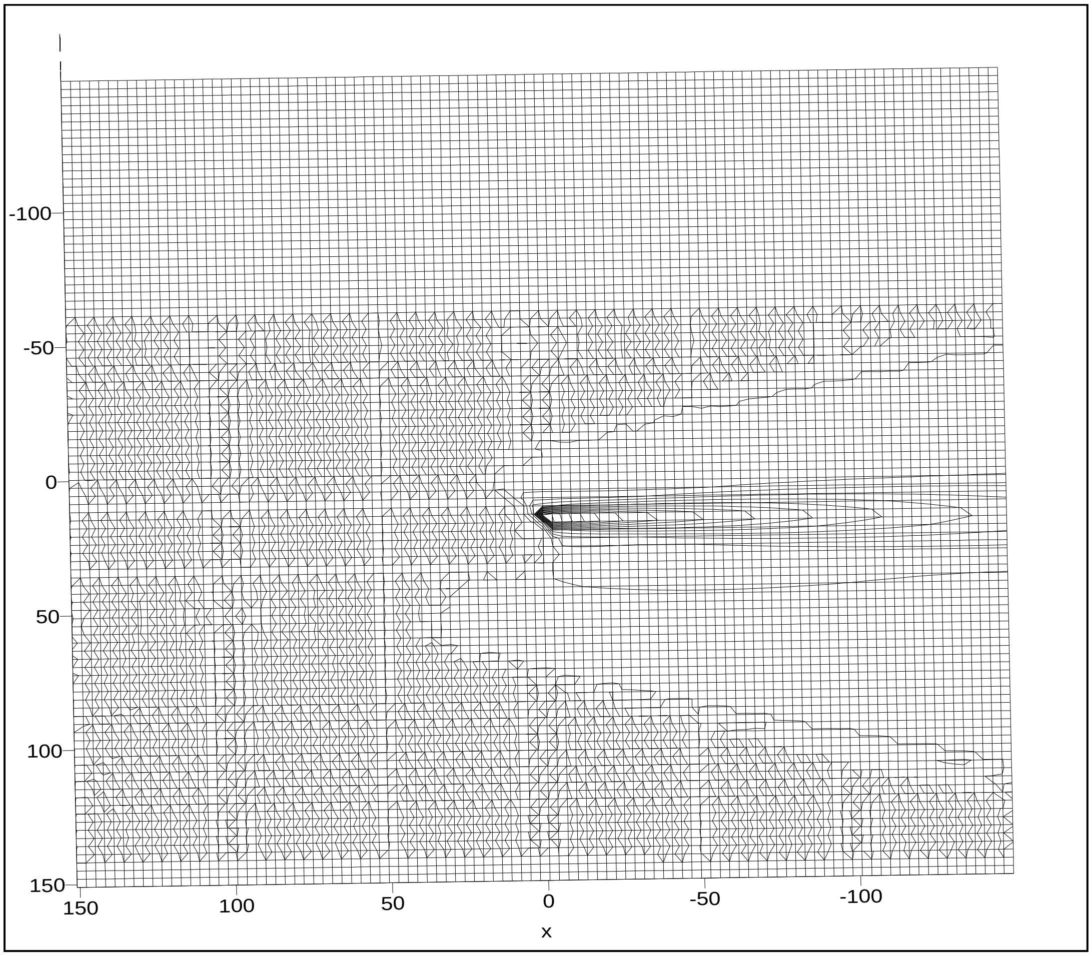

(U) Figure 10: Top-Down View of the Downwind Concentration Footprint.

The parametric matrix was run to explore the contributions of several different factors that could affect the results. Two measures of the results were used to portray the results. The first metric was the area that was at risk of the threshold concentration for lethal, severe, or mild effects at the 16th percentile level for the one-hour of exposure with a breathing rate of 60 liters/minute. This metric is presented below in the cells of the table by the mean value physically above the standard deviation. The second metric captured the percent of cases where there was zero area where vapor exposure was above the three casualty thresholds.

The results below represent the results from all cases of the parametric matrix. Since contamination density was such an important issue in determining the downwind concentration results, the results for 5,000 mg/m^2 are presented in Appendix A, 500 mg/m^2 results are presented in Appendix B, and 50 mg/m^2 results are presented in Appendix C.

The first table shows the results for each of the aircraft examined. For example, for the A-10 aircraft, the mean area covered at the lethal casualty threshold was 3.79 m^2 with a standard deviation of 60.290 m^2. The percent of cases with zero area above this threshold level was 98.02%.

Note the general trend, which shows that the area covered above the casualty thresholds increased substantially in going from lethal and severe casualty thresholds to mild casualty thresholds. However, the percent of cases with zero area was highest for lethal and least for mild effects levels. Table 15 shows the relative differences between the geometry, surface area, and height above ground of the surfaces of the aircraft. A review of the larger aircraft compared to the smaller aircraft does not necessarily mean that these metrics scale with aircraft size because the height above ground reduced the ground-level concentration levels.

(U) Table 15: Parametric Results by Aircraft.

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Parametric Results by Aircraft						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Aircraft	Lethal	Severe	Mild	Lethal	Severe	Mild
Fighter/Attack						
A-10	3.79 60.290	7.03 85.870	141.39 686.351	98.02	96.16	83.64
F-15	2.22 43.710	4.22 72.609	118.34 630.722	98.87	98.04	87.65
F-16	1.63 32.562	3.20 55.023	103.64 565.805	98.87	98.06	87.77
FA-22	3.07 55.842	5.57 81.900	129.21 649.119	98.42	97.11	85.66
F-35	0.00 0.134	0.01 0.274	162.96 763.705	99.96	99.90	84.64
F-117	4.69 74.114	8.60 102.548	152.91 705.051	97.93	95.94	83.12
Bomber						
B-1	14.17 200.554	25.43 273.839	367.65 1,493.609	98.17	96.68	82.44
B-2	38.11 369.054	72.05 505.119	614.61 1,954.752	96.97	93.58	76.76
B-52	5.71 120.972	13.58 198.741	295.54 1,500.916	99.08	98.38	87.88
Cargo/Tanker/Utility						
C-5	11.28 217.754	24.68 321.032	420.56 2,158.923	99.22	98.24	89.98
C-17	7.45 146.101	17.16 224.898	269.24 1,527.536	99.23	98.47	91.94
C-20	7.47 107.713	13.77 151.234	223.08 956.811	98.16	96.54	83.29
C-21	2.65 44.353	5.02 66.116	116.43 591.352	98.19	96.46	84.99
C-32	15.82	29.82	350.74	97.21	94.16	78.32

	187.647	261.309	1,418.790			
C-37	7.11 103.981	13.20 146.803	218.22 969.984	98.37	97.01	84.91
C-40	14.71 166.892	27.89 231.113	318.79 1,241.852	96.59	93.19	77.43
C-130	4.74 81.948	10.89 138.307	231.81 1,165.442	98.30	97.02	84.96
C-130J-30	5.74 98.144	12.84 152.253	244.42 1,213.106	97.95	96.37	84.07
C-141	7.76 137.461	16.41 219.733	312.44 1,543.882	98.98	98.27	87.64
KC-10	11.52 180.792	20.83 269.304	365.17 1,698.650	99.02	98.39	87.67
KC-135	9.50 151.980	16.21 215.866	299.19 1,352.533	98.52	97.21	84.06
U-2	7.03 98.183	12.97 134.226	193.44 854.436	97.10	94.39	80.91
E-3	9.35 151.051	16.31 213.334	301.57 1,352.671	98.46	97.14	83.89
E-4	16.76 260.610	29.92 374.260	463.92 2,129.289	98.93	97.99	86.89
E-8	12.62 194.445	21.93 269.038	356.16 1,531.034	98.36	96.90	82.99
OC-135	9.31 151.704	16.10 218.046	298.18 1,366.906	98.57	97.31	84.19
RC-135	9.31 151.704	16.10 218.046	298.18 1,366.906	98.57	97.31	84.19
Unmanned Aerial Vehicle (UAV)						
MQ-1	0.64 12.083	1.39 24.089	64.67 419.106	99.34	99.10	92.42
RQ-4	6.04 81.747	11.33 113.664	168.77 784.358	96.82	93.78	80.27
Helicopter						
UH-1	0.06 2.187	0.10 4.000	19.27 293.634	99.82	99.79	98.45
MH-53	1.02 25.971	2.38 45.710	108.20 643.492	99.34	98.77	90.28
HH-60	1.95 39.695	3.88 67.909	115.32 628.996	99.06	98.37	89.00
Trainer						
T-1	3.07 52.924	5.66 75.777	130.39 639.112	98.37	97.18	85.72
T-6	1.34 22.185	2.66 37.845	80.97 468.468	98.00	96.46	86.67
T-37	1.66 26.881	2.96 41.591	81.33 465.264	98.67	97.88	89.38
T-38	0.04 1.717	0.15 4.927	41.17 336.754	99.84	99.73	96.07
T-43	3.58	8.07	194.75	98.60	97.46	85.19

	63.177	111.032	987.134			
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

Table 16 contains the results for the three agents examined. The results followed the general tendencies of the data used to generate the mass flux. GD was the most capable of producing lethal and severe effects levels (especially at early times, which will be shown in a later table). HD produced the smallest lethal and mild effects levels. The percent of zero cases was highest for lethal and severe effects levels of VX, while the mild effects levels of GD and VX are much lower than HD.

(U) Table 16: Parametric Results by Agent.

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Parametric Results by Agent						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Agent	Lethal	Severe	Mild	Lethal	Severe	Mild
GD	20.96 229.917	34.09 315.647	440.60 1,715.415	96.13	94.99	79.49
HD	0.01 0.357	5.83 96.766	5.88 96.867	99.94	97.32	97.26
VX,	0.35 9.339	0.65 15.196	232.38 1,046.590	99.38	99.16	80.70
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

Table 17 contains the results for the three contamination densities examined. These results showed a very strong relationship based on the contamination density in both the mean results, as well as the zero area cases. While the 50 mg/m^2 and 500 mg/m^2 showed low mean values and high percent zero cases when compared to the 5,000 mg/m^2 cases, the average across the contamination density cases strongly favored the results generated by the 5,000 mg/m^2 case.

(U) Table 17: Parametric Results by Contamination Level.

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Parametric Results by Contamination Level						
Contamination Level (mg/m^2)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases With Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
50	0.00 0.103	0.00 0.220	4.78 81.801	99.98	99.95	97.49
500	0.56 18.409	1.31 36.288	85.43 575.571	99.39	98.90	89.12
5,000	20.76 229.388	39.25 327.971	588.66 1,898.353	96.08	92.61	70.84
All	7.11 133.213	13.52 191.377	226.29 1,175.008	98.48	97.16	85.82

The following chart shows the percent of cases where the lethal, severe, and mild area coverage was zero over the range of contamination densities that were studied.

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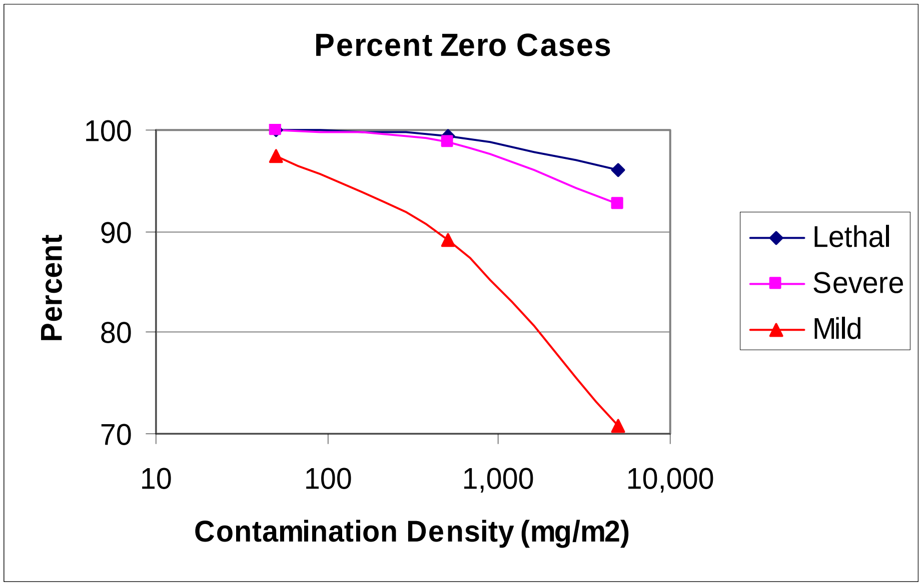

(U) Figure 11: Percent Zero Cases vs. Contamination Density.

Table 18 contains the results for the six times after contamination. These results showed a significant decrease in mean area covered, and an increase in the percent of zero cases as time increased from 0.5 hours through to two hours, and then additional changes with increasing time from four to 24 hours.

(U) Table 18: Parametric Results by Time After Contamination.

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Parametric Results by Time After Contamination						
Time (hour)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0.5	40.46 321.952	73.34 455.792	827.63 2,379.450	93.54	89.19	65.39
1	1.62 36.249	4.98 73.440	303.41 1,176.645	98.51	96.77	77.49
2	0.51 13.006	2.69 47.867	157.90 741.954	99.15	97.58	83.56
4	0.03 1.103	0.07 2.045	33.99 316.782	99.86	99.69	94.78
8	0.02 0.908	0.05 1.681	29.09 286.289	99.87	99.76	95.47
24	0.00 0.140	0.00 0.245	5.70 89.691	99.96	99.94	98.23
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

Table 19 contains the results for the six standoff distances from where the aircraft were examined (Note: the standoff distances were calculated along the downwind axis). While there was a tendency to decrease mean area coverage and increase percent zero cases as standoff distances increased, the biggest changes were not observed until 250 feet.

(U) Table 19: Parametric Results by Standoff Distance.

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Parametric Results by Standoff Distance						
Standoff distance (feet)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
10	11.64 169.304	21.98 242.641	338.35 1,466.206	96.31	93.06	73.96
25	10.57 163.181	20.02 234.049	320.31 1,421.096	97.55	95.42	79.36
50	9.30 154.882	17.70 222.376	295.68 1,355.380	98.45	97.06	83.59
100	7.34 138.128	14.08 198.912	251.50 1,225.861	99.07	98.27	87.64
250	3.40 87.989	6.61 127.181	136.35 818.905	99.61	99.30	92.71
500	0.38 16.628	0.74 23.732	15.53 157.668	99.90	99.82	97.67
Combined 5,000, 500, and 50 mg/m^2 contamination densities						

Table 20 contains the results for the nine relative wind angles that were examined. These results showed an increase in risk at 0 and 90 degrees (where the long axis of the aircraft [or the wings] were along the wind direction). This was related to the nature of the Gaussian representation discussed in the contribution to generating the steep concentration gradient crosswind.

(U) Table 20: Parametric Results by Relative Wind Angle.

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Parametric Results by Relative Wind Angle						
Angle (degree)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0	18.67 247.481	34.75 338.115	357.50 1,381.707	97.92	95.97	81.23
30	6.06 126.438	11.85 189.734	240.17 1,243.033	98.92	97.90	87.10
45	5.47 113.458	10.84 171.835	214.47 1,160.015	98.88	97.83	87.40
60	5.17 106.331	10.23 158.872	211.77 1,199.905	98.89	97.82	87.53
90	11.79 188.412	22.58 279.230	391.68 1,923.280	97.52	95.22	81.04
120	4.13 77.162	7.98 111.992	173.86 885.250	98.61	97.50	87.40
135	4.16 75.089	7.89 108.083	158.47 790.182	98.54	97.39	87.21
150	4.20 74.142	7.77 105.032	145.56 713.272	98.56	97.43	87.09
180	4.30 74.259	7.79 103.114	143.11 710.269	98.50	97.32	86.38
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

Table 21 contains the results for the six PSCs that were examined. As stability increased from A to F, the mean area coverage increased and the percent of cases with zero area coverage decreased.

(U) Table 21: Parametric Results by Six PSCs.

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Parametric Results by Pasquill Stability Category						
Pasquill Stability Category	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
A	1.61 38.053	3.45 66.143	196.61 1,385.916	98.97	98.32	90.69
B	2.98 69.215	6.25 116.298	199.02 1,247.487	98.90	98.07	89.02
C	5.16 109.101	10.28 168.886	217.20 1,183.610	98.64	97.50	86.77
D	7.45 141.101	14.28 209.718	226.60 1,116.905	98.45	97.01	84.97
E	11.30 181.220	20.75 249.956	255.82 1,090.737	98.14	96.38	82.90
F	14.14 188.320	26.12 257.863	262.47 982.289	97.80	95.65	80.57
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

Table 22 contains the results for the three windspeeds that were examined. As windspeed increased, the mean area coverage decreased and the zero area cases increased. This was consistent with the Gaussian concentration equation.

(U) Table 22: Parametric Results by Windspeed.

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Parametric Results by Windspeed						
Windspeed (m/sec)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases With Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
1	16.46 211.208	31.41 302.453	430.01 1,680.522	97.06	94.60	79.03
3	3.39 80.607	6.28 114.011	152.79 889.355	99.02	98.01	87.72
5	1.47 44.697	2.88 70.098	96.06 680.415	99.38	98.86	90.71
Combined 5,000, 500, and 50 mg/m^2 contamination densities.						

The next set of figures show the standoff distance for the six measures of effects that have been examined. Figure 12 shows the result for the three agents and the three levels of lethal mean area. This figure shows that at the four-hour point, the standoff distance of 10 feet satisfied the criteria of having no lethal mean areas that were greater than either 10, 100, or 1,000 m^2.

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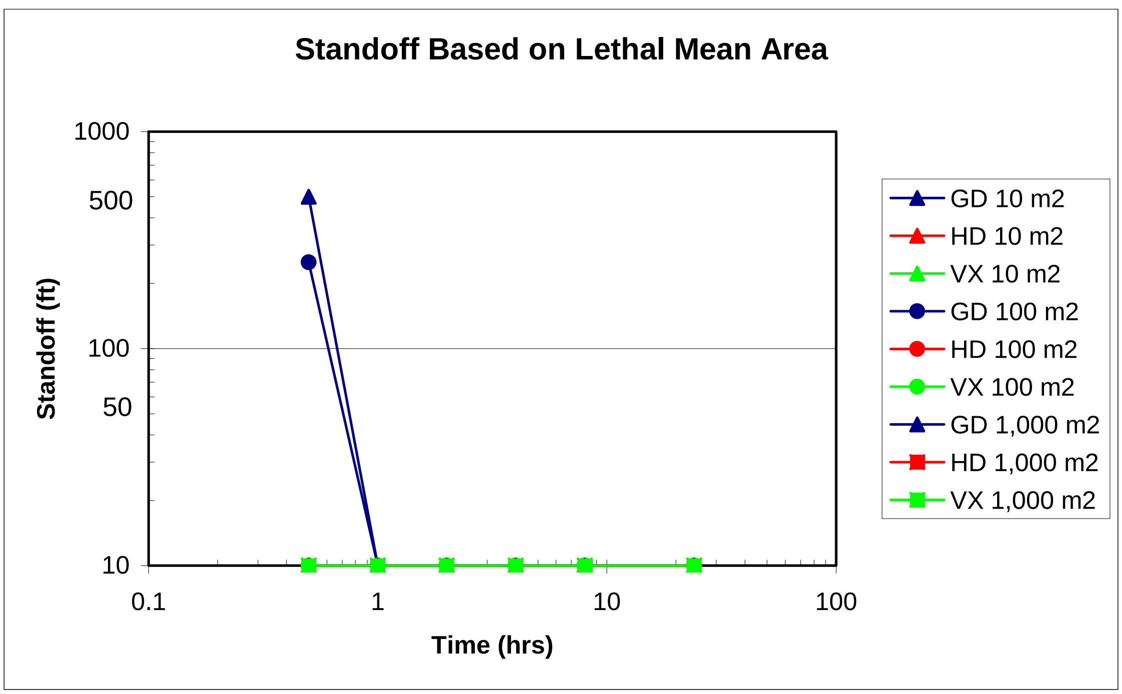

(U) Figure 12: Standoff Distance Based on Lethal Mean Area. It is important to note that many of the cases are stacked, but they satisfy the 10-foot rule.

Figure 13 shows the results for the three agents and the three levels of severe mean area. This figure showed that at the four-hour point, the standoff distance of 10 feet satisfied the criteria of no severe mean areas greater than either 10, 100, or 1,000 m^2.

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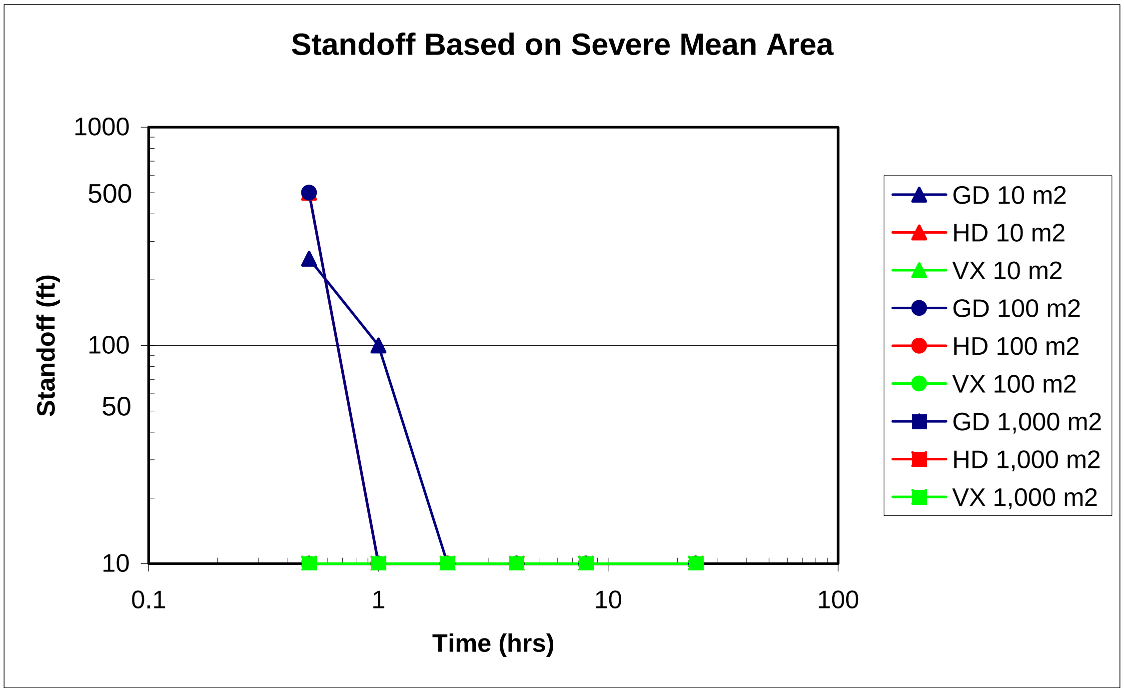

(U) Figure 13: Standoff Distance Based on Severe Mean Area.

Figure 14 shows the result for the three agents and the three levels of mild mean area. This figure shows that at the four-hour point, the standoff distance of 10 feet satisfied the criteria that there were no mild mean areas greater than either 10, 100, or 1,000 m^2, except for the VX results at 10 and 100 m^2.

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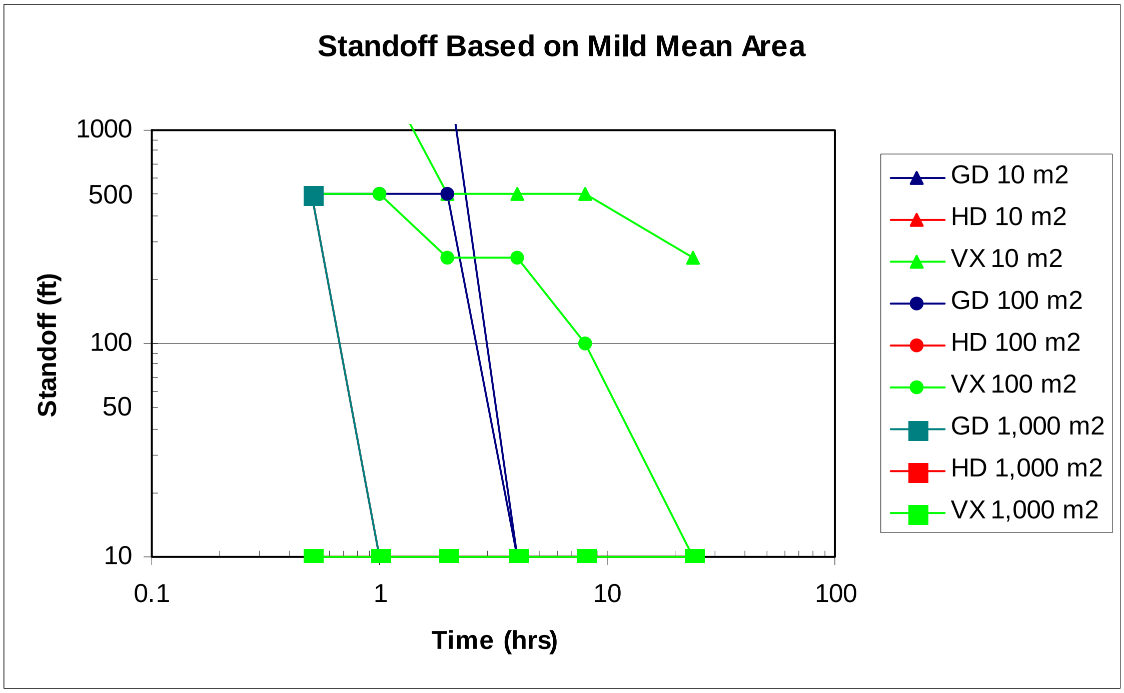

(U) Figure 14: Standoff Distance Based on Mild Mean Area.

Figure 15 shows the result for the three agents and the five levels of lethal effects based on zero area coverage. This figure shows that at the four-hour point, the standoff distance of 10 feet satisfied the criteria of 100% lethal zero area coverage for GD, 100% lethal zero area coverage for HD, and at least 95% lethal zero area coverage for VX.

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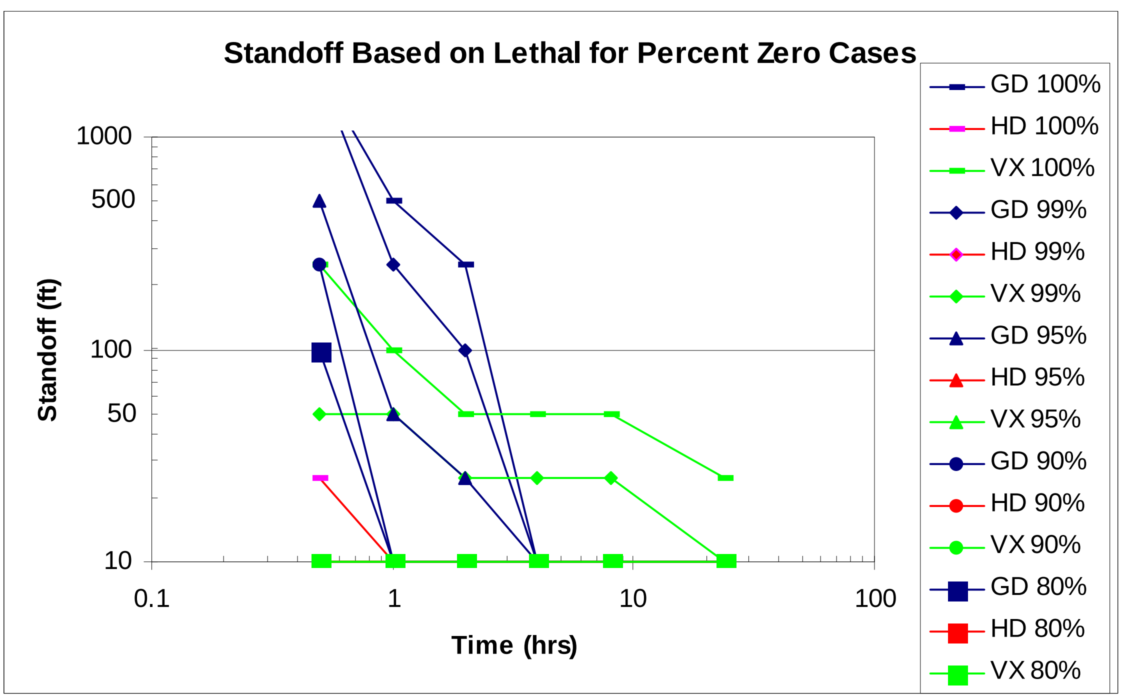

(U) Figure 15: Standoff Distance Based on Lethal Effects for Percent Zero Cases.

Figure 16 shows the result for the three agents and the five levels of severe effects based on the zero area coverage. This figure shows that at the four-hour point, the standoff distance of 10 feet satisfied the criteria of 100% severe zero area coverage for GD, at least 95% severe zero area coverage for HD, and at least 95% severe zero area coverage for VX.

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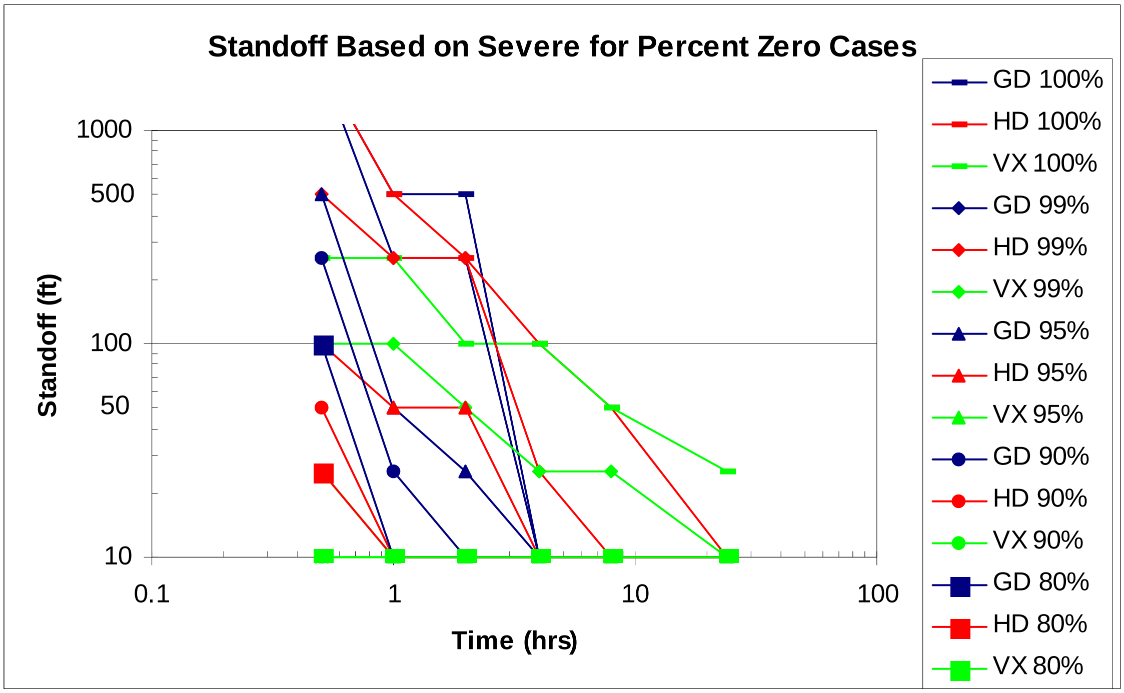

(U) Figure 16: Standoff Distance Based on Severe Effects for Percent Zero Cases.

Figure 17 shows the result for the three agents and the five levels of severe effects based on the zero area coverage. This figure shows that at the four-hour point, the standoff distance of 10 feet satisfied the criteria of 100% lethal zero area coverage for GD, at least 95% mild zero area coverage for HD, and no cases were in the mild zero area coverage for VX that were below 80%.

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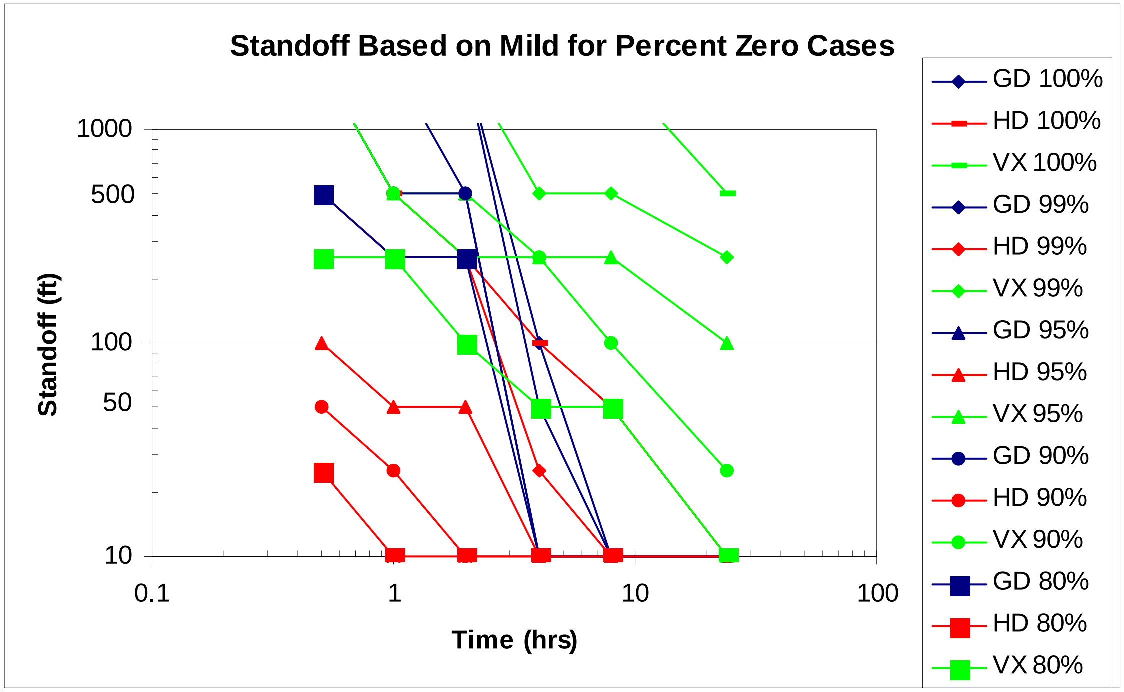

(U) Figure 17: Standoff Distance Based on Mild Effects for Percent Zero Cases.

Based on the results generated, the standoff distance that worked for GD or the distance that provided at least 95% of the zero cases was 10 feet for lethal, severe, or mild effects levels at three to 24 hours after contamination with 50, 500, and 5,000 mg/m^2 of agent.

(U) Table 23: Standoff Distance for GD.

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Standoff Distance for GD (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	100	50	10	10	10
	100	100	50	10	10	10
	1,000	100	50	10	10	10
*Results for approximately three hours after all three contamination densities.						

Based on the results generated, the standoff distance that worked for HD that provided at least 95% of zero cases was 10 feet for lethal, severe, or mild effects levels at three to 24 hours after contamination with 50, 500, and 5,000 mg/m^2 of agent.

(U) Table 24: Standoff Distance for HD.

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Standoff Distance for HD (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	100	25	10	10	10
	100	100	25	10	10	10
	1,000	100	25	10	10	10
Mild						
	10	100	25	10	10	10
	100	100	25	10	10	10
	1,000	100	25	10	10	10
*Results for approximately three hours after all three contamination densities.						

Based on the results generated, the standoff distance that worked for VX that provided at least 95% of zero cases was 250 feet for lethal, severe, or mild effects levels at three to 24 hours after contamination with 50, 500, and 5,000 mg/m^2 of agent.

(U) Table 25: Standoff Distance for VX.

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Standoff Distance for VX (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	50	25	10	10	10
	100	50	25	10	10	10
	1,000	50	25	10	10	10
Severe						
	10	100	25	10	10	10
	100	100	25	10	10	10
	1,000	100	25	10	10	10
Mild						
	10	> 500	500	250	250	100
	100	> 500	500	250	250	100
	1,000	> 500	500	250	250	100
*Results for approximately three hours after all three contamination densities.						

Conclusions

The use of the ORM approach with a Risk Rating of "Low" is desired. Choosing a standoff distance that produced more than 90% zero cases resulted in a hazard probability of "Unlikely," and by choosing an effects level of "Mild," this resulted in a hazard severity of "Marginal" for GD and VX, and "Critical" for HD, which satisfied the criteria of generating a "Low" Risk Rating. The use of the percent cases with zero area was a VERY conservative measure of the hazard probability as discussed above. This method was conservative for four reasons: 1) the percentile of airbase hazard area based on 500 mg/m^2 contamination density was at least the 95th percentile for the entire base; 2) the area covered by the mild area above the threshold represented a maximum of 0.0003% of the base area; 3) the fraction of the nearly two million cases that had zero area above threshold was used as the standard, not just the number of cases above the threshold value; and 4) 60 m/l for one hour is average for an adult male running at 5mph; this may overestimate the dosage for lower activity levels[18].

In analyzing the data, several time domains were identified in the data: from the time of attack to one hour after contamination; after the first hour to three hours after contamination; between three hours and 24 hours after contamination; and then after 24 hours after contamination.

The first time domain, from the time of attack to one hour after the contamination, represented the initial period. To analyze this period, the results at 30 minutes were examined. This time period resulted in the highest concentration produced by the attack, as seen in the mass flux experimental data. This time period was also significant for several reasons. Establishing the completion of deposition (on any particular location of the base) is difficult, and the C-CW CONOPS recommends that the base remain under overhead cover during a significant portion of this time period. Then, the base post-attack recovery occurs in the time period during which the areas that were contaminated would be established. The application of the "rule" requires aircraft or other large painted metal surfaces to be in a zone of the airbase that has been declared a MOPP 2 area, based on the base post-attack reconnaissance surveys. This implies that the aircraft is moved from the location of contamination, or that is was located in an uncontaminated zone. In the first case, this assessment will require time most likely in excess of one hour, and in the second case, the aircraft is not contaminated.

Therefore, the initial time domain of the first hour after the attack is outside the domain of this analysis, and the rule would be to remain protected in MOPP 4.

In the second time domain, after the first hour and until three hours after contamination, there were circumstances where a contaminated aircraft could be in a location where MOPP 2 could be recommended for the zone after a chemical attack. To assess this domain, the one-hour hazard data was used. Table 26 summarizes the results for the three agents and hazard levels at the five levels of percent zero cases.

(U) Table 26: Standoff Distance for 500 mg/m² at One Hour After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	50	25	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	50	25	10	10	10
	HD	50	25	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	> 500	500	500	250	100
	HD	50	25	10	10	10
	VX	> 500	500	250	250	100
*Results for approximately one-hour after contamination at 500 mg/m².						

The 95% zero case mild results for 500 mg/m² showed a 500-foot standoff distance for GD, a 10-foot standoff distance for HD, and a 250-foot standoff distance for VX. To simplify, a 500-foot standoff distance is recommend for the period of time between one and three hours.

(U) Table 27: Standoff Distance for 500 mg/m² between Three and 24 hours after Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	250	100	50	25	10
*Results for approximately three-hour after contamination at 500 mg/m². The mean area covered results were identical for the three-hour results.						

If a good estimate of the contamination density can be made from M8 paper that was located on or very closely associated to the aircraft during contamination, the recommended standoff distance could be reduced to 50 feet. However, this procedure would require significant training in how to interpret M8 paper results to estimate contamination density. Examples of M8 paper with different contamination densities and droplet sizes are provided as examples in Appendix D.

The third time domain is the period between three and 24 hours after the attack. The 95% zero case mild results for 500 mg/m^2 showed a 10-foot standoff distance for GD, a 10-foot standoff distance for HD, and a 50-foot standoff distance for VX. To simplify, a 50-foot standoff distance is recommend for the period of time between three and 24 hours.

(U) Table 28: Standoff Distance for 500 mg/m^2 at 24 Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	50	25	10	10	10
* Results for approximately 24-hours after contamination at 500 mg/m^2						

At 24 hours after contamination, gloves (either work or protective gloves) are recommended whenever working with the surfaces of the aircraft.

Appendix A
Parametric Results for 5,000 mg/m^2 Contamination Density

This annex provides the parametric results for the 5000 mg/m^2 contamination density by aircraft, agent, time after contamination, standoff distance, relative wind angles, PSCs, and wind speeds.

(U) Table A1: Parametric Results by Aircraft for 5,000 mg/m^2 Contamination Density.

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Parametric Results by Aircraft						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Aircraft	Lethal	Severe	Mild	Lethal	Severe	Mild
Fighter/Attack						
A-10	11.1 103.9	20.5 147.5	377.1 1,123.7	94.9	89.9	67.2
F-15	6.6 75.5	12.5 125.3	318.8 1,036.4	97.0	94.9	74.4
F-16	4.8 56.3	9.5 95.0	283.4 935.3	97.0	94.8	74.5
FA-22	9.1 96.4	16.4 141.1	345.0 1,061.3	95.8	92.4	70.8
F-35	0.0 0.2	0.0 0.5	435.8 1,245.2	99.9	99.7	69.2
F-117	13.7 127.7	24.9 175.9	400.1 1,141.9	94.7	89.4	66.6
Bomber						
B-1	41.8 345.2	74.6 468.9	938.0 2,363.9	95.3	91.4	65.2
B-2	109.7 629.3	205.6 848.2	1,527.5 2,988.8	92.2	83.1	54.5
B-52	17.0 209.0	40.0 342.1	770.2 2,426.3	97.5	95.7	74.2
Cargo/Tanker/Utility						
C-5	32.3 373.9	70.9 548.1	1,074.0 3,462.6	98.0	95.3	78.5
C-17	21.5 251.3	49.7 384.8	683.6 2,464.5	98.0	95.8	82.2
C-20	22.2 185.6	40.4 259.4	581.5 1,537.3	95.3	90.8	65.6
C-21	7.8 76.5	14.7 113.8	316.0 973.3	95.1	90.4	68.7
C-32	45.3 321.2	85.0 443.7	879.9 2,245.1	93.1	85.2	58.5
C-37	21.1 179.2	38.9 251.9	573.8 1,565.6	95.5	91.8	66.5
C-40	42.0 285.5	79.3 391.7	803.8 1,967.2	91.5	82.9	56.8

C-130	13.8 141.3	31.7 237.5	612.5 1,899.7	95.8	92.7	70.4
C-130J30	16.4 168.7	36.7 260.1	636.1 1,969.5	95.2	91.6	70.0
C-141	22.9 237.1	48.0 377.1	810.0 2,489.9	97.2	95.3	73.7
KC-10	33.9 311.3	60.9 461.8	943.7 2,716.8	97.3	95.5	72.0
KC-135	28.2 262.2	47.6 371.2	779.3 2,169.1	96.3	93.0	67.8
U-2	20.4 168.9	37.4 229.7	505.2 1,380.2	92.7	85.9	62.4
E-3	27.7 260.6	47.9 366.8	782.0 2,166.5	96.2	92.8	67.6
E-4	49.0 448.2	87.1 641.2	1,184.9 3,382.9	97.1	94.4	70.6
E-8	37.3 335.3	64.3 462.0	920.8 2,439.7	95.9	92.2	66.3
OC-135	27.6 261.7	47.2 375.0	776.8 2,194.7	96.4	93.2	68.4
RC-135	27.6 261.7	47.2 375.0	776.8 2,194.7	96.4	93.2	68.4
UAV						
MQ-1	1.9 20.9	4.2 41.6	186.5 706.3	98.0	97.3	80.3
RQ-4	17.5 140.7	32.7 194.6	451.5 1,280.7	92.1	84.4	61.4
Helicopter						
UH-1	0.2 3.8	0.3 6.9	56.6 506.2	99.5	99.4	96.9
MH-53	3.1 44.9	7.1 78.9	291.8 1,063.7	98.2	96.7	79.0
HH-60	5.9 68.6	11.6 117.2	313.7 1,037.4	97.3	95.5	75.4
Trainer						
T-1	9.1 91.3	16.6 130.4	352.2 1,047.2	95.6	92.3	69.8
T-6	4.0 38.3	7.9 65.2	229.5 783.2	94.7	90.7	71.4
T-37	5.0 46.4	8.8 71.7	230.0 776.9	96.1	93.9	75.1
T-38	0.1 3.0	0.4 8.5	119.3 573.2	99.5	99.2	89.7
T-43	10.5 109.0	23.5 191.0	512.4 1,607.8	96.5	93.6	71.1
5,000 mg/m^2 contamination density.						

(U) Table A2: Parametric Results By Agent.

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Parametric Results by Agent						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Agent	Lethal	Severe	Mild	Lethal	Severe	Mild
t-GD	61.2 393.9	98.4 537.4	1,080.5 2,692.9	90.3	87.8	63.9
HD	0.0 0.6	17.4 167.0	17.5 167.2	99.8	92.6	92.4
VX, t-VX	1.0 16.2	1.9 26.3	667.9 1,719.7	98.2	97.5	56.3
5,000 mg/m^2 contamination density.						

(U) Table A3: Parametric Results By Time After Contamination.

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Parametric Results by Time After Contamination						
Time (hour)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0.5	118.0 547.6	212.2 765.8	2,015.1 3,608.0	84.2	73.8	40.4
1	4.9 62.7	14.9 126.6	857.1 1,899.8	95.7	90.7	52.7
2	1.5 22.5	8.0 82.6	454.9 1,222.9	97.5	93.0	62.1
4	0.1 1.9	0.2 3.5	101.1 542.4	99.6	99.1	86.5
8	0.1 1.6	0.1 2.9	86.7 490.8	99.6	99.3	88.3
24	0.0 0.2	0.0 0.4	17.1 154.7	99.9	99.8	95.0
5,000 mg/m^2 contamination density.						

(U) Table A4: Parametric Results By Six Standoff Distances.

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Parametric Results by Standoff Distance						
Standoff distance (feet)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
10	18.4 291.0	36.3 414.5	575.6 2,340.4	90.9	82.8	53.0
25	30.8 280.6	58.0 400.2	828.6 2,271.8	93.7	88.1	59.2
50	27.2 266.5	51.5 380.6	769.1 2,171.3	95.9	92.1	65.0
100	21.6 237.9	41.1 341.0	659.4 1,972.6	97.4	95.2	71.8
250	10.1 151.8	19.4 218.6	362.9 1,335.9	98.9	98.0	82.0
500	1.1 28.7	2.2 40.8	41.4 262.1	99.7	99.5	94.1
5,000 mg/m^2 contamination density.						

(U) Table A5: Parametric Results By Nine Relative Wind Angles.

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Parametric Results by Relative Wind Angle						
Angle (degree)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0	53.9 424.2	99.2 573.9	884.9 2,148.6	94.7	89.3	61.8
30	17.9 218.2	34.9 326.7	629.8 2,010.8	97.2	94.5	72.6
45	16.1 195.7	31.9 295.7	561.3 1,879.5	97.1	94.4	73.5
60	15.2 183.4	30.0 273.1	555.0 1,954.5	97.1	94.3	73.9
90	34.4 324.6	65.6 479.5	1,016.2 3,093.5	94.1	88.4	64.0
120	12.1 132.9	23.3 192.2	462.4 1,442.7	96.3	93.4	73.7
135	12.2 129.3	23.0 185.4	420.8 1,287.7	96.1	93.1	73.3
150	12.3 127.7	22.7 180.0	385.4 1,162.9	96.2	93.2	73.0
180	12.6 127.9	22.5 176.0	382.1 1,165.4	96.0	93.0	71.8
5,000 mg/m^2 contamination density.						

(U) Table A6: Parametric Results By the Six PSCs.

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Parametric Results by Pasquill Stability Category						
Pasquill Stability Category	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
A	4.8 65.8	10.3 114.2	562.2 2,341.0	97.1	95.2	78.8
B	8.9 119.6	18.5 200.7	547.4 2,068.6	97.0	94.7	75.7
C	15.3 188.5	30.3 291.2	577.8 1,916.5	96.4	93.3	72.0
D	22.0 243.6	42.0 361.0	585.6 1,772.9	96.0	92.3	69.1
E	33.1 312.1	60.2 427.9	635.3 1,687.3	95.4	90.9	66.2
F	40.6 322.3	74.2 436.8	623.6 1,481.3	94.6	89.2	63.1
5,000 mg/m^2 contamination density.						

(U) Table A7: Parametric Results By Three Windspeeds.

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Parametric Results by Windspeed						
Windspeed (m/sec)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
1	47.8 362.4	90.5 515.0	1,101.1 2,642.6	92.6	86.2	59.4
3	10.1 139.4	18.7 196.8	402.7 1,460.2	97.4	94.8	73.8
5	4.4 77.3	8.6 121.2	262.1 1,136.6	98.2	96.9	79.3
5,000 mg/m^2 contamination density.						

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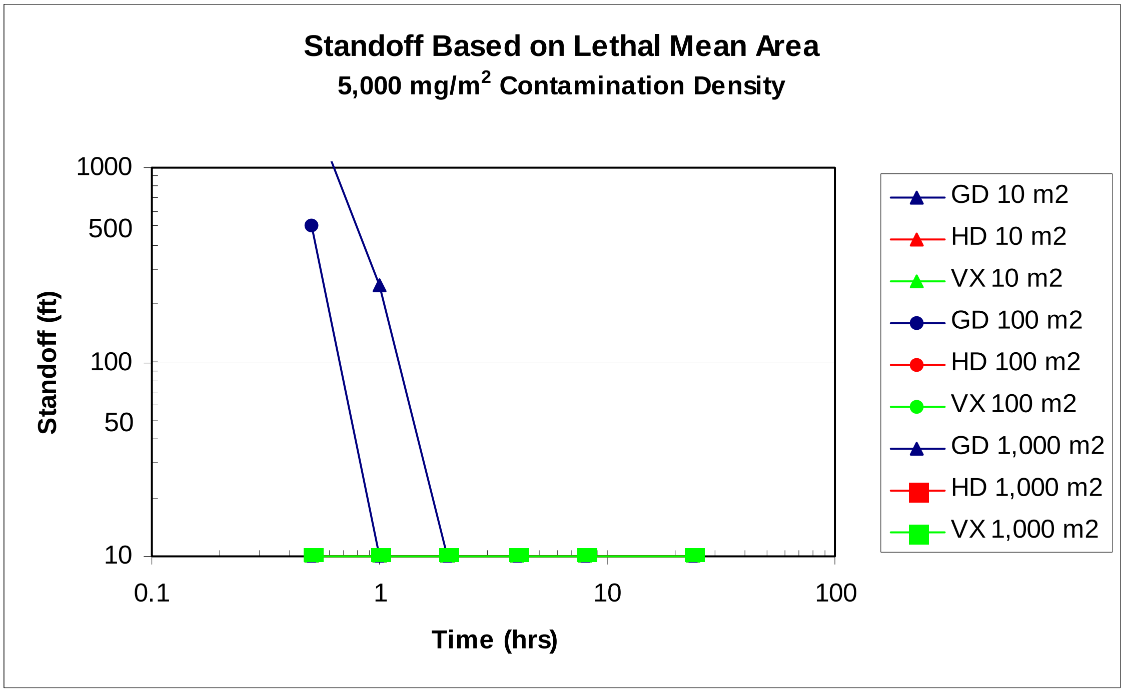

(U) Figure A1: Standoff Distance Based on Lethal Mean Area.

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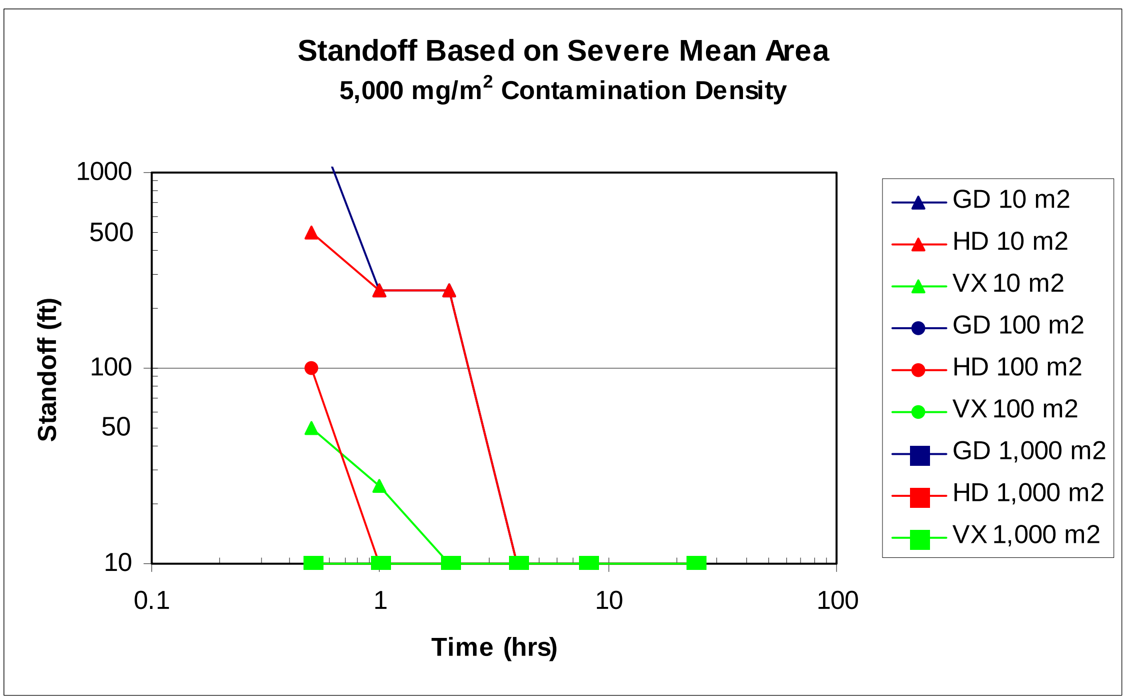

(U) Figure A2: Standoff Distance Based on Severe Mean Area.

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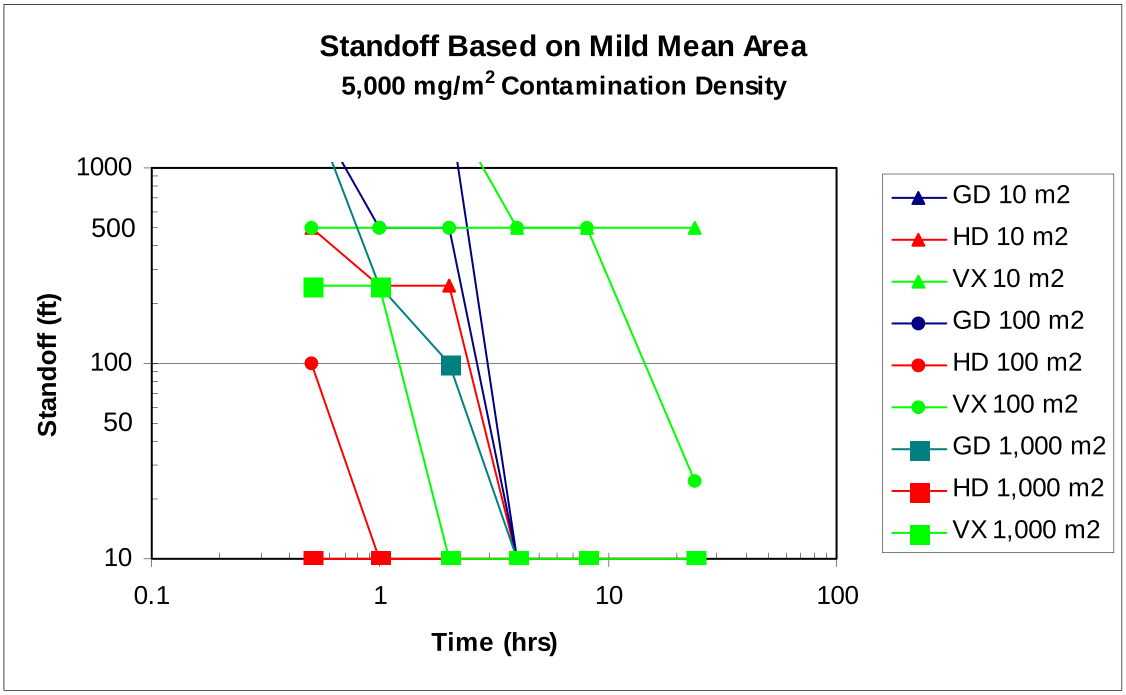

(U) Figure A3: Standoff Distance Based on Mild Mean Area.

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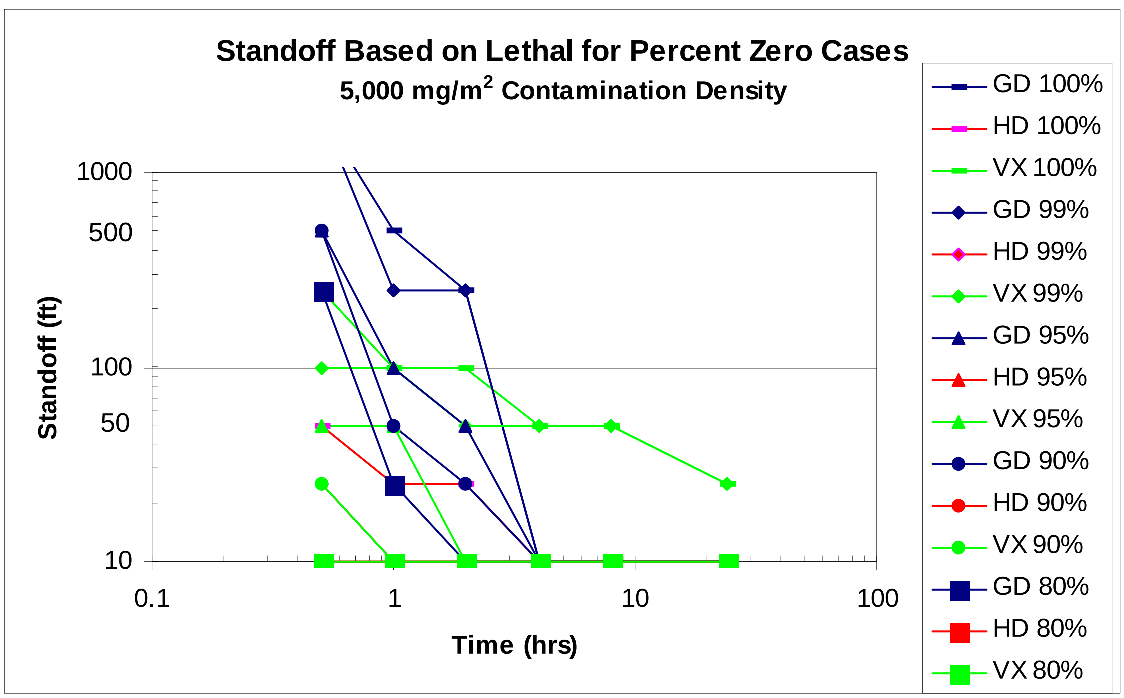

(U) Figure A4: Standoff Distance Based on Lethal for Percent Zero Cases.

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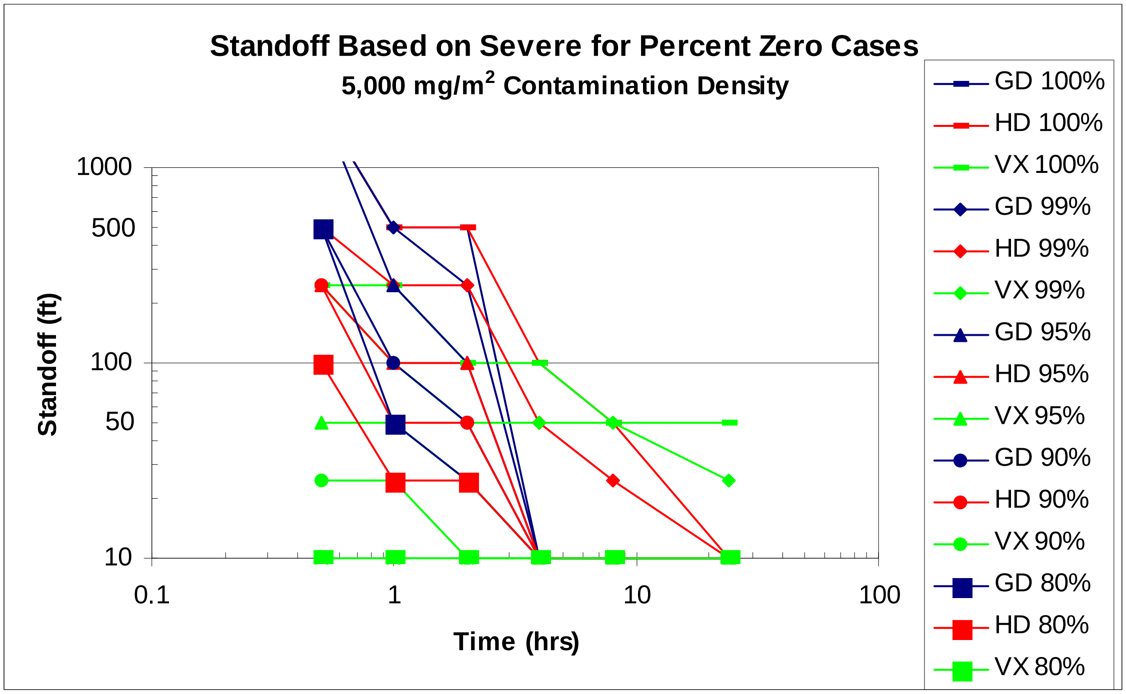

(U) Figure A5: Standoff Distance Based on Severe for Percent Zero Cases.

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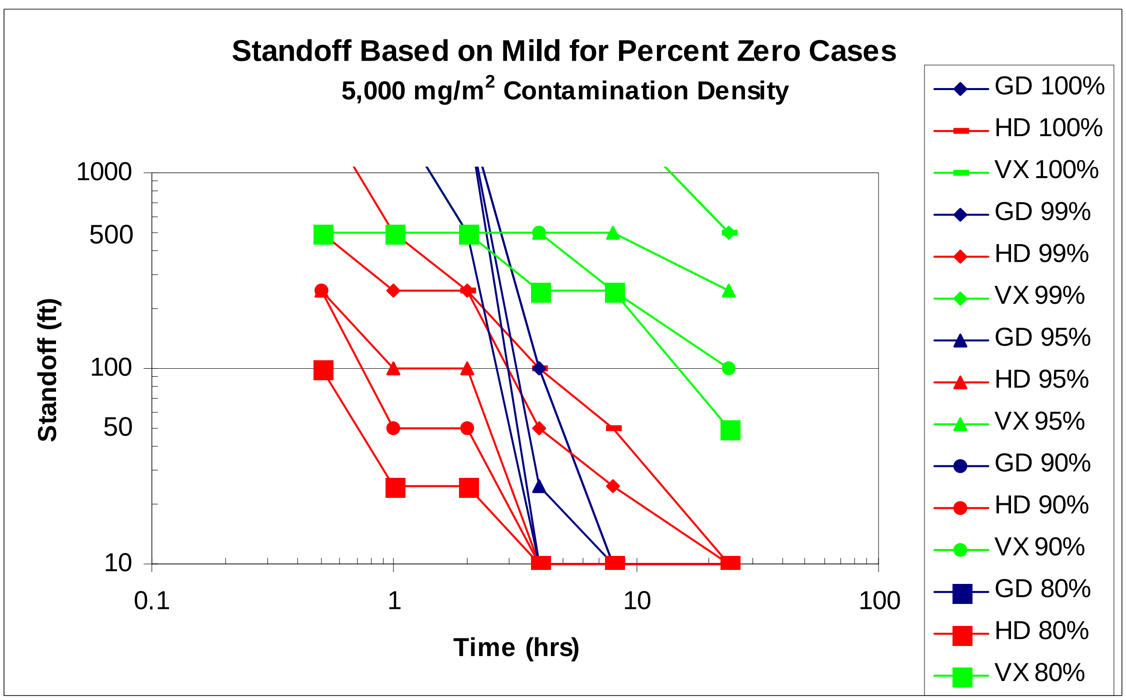

(U) Figure A6: Standoff Distance Based on Mild for Percent Zero Cases.

(U) Table A8: Standoff Distance for GD.

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Standoff Distance for GD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	100	100	25	10	10
	100	100	100	25	10	10
	1,000	100	100	25	10	10
*Results for approximately three hours after contamination at 5,000 mg/m^2.						

(U) Table A9: Standoff Distance for HD.

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Standoff Distance for HD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	100	50	10	10	10
	100	100	50	10	10	10
	1,000	100	50	10	10	10
Mild						
	10	100	50	10	10	10
	100	100	50	10	10	10
	1,000	100	50	10	10	10
*Results for approximately three hours after contamination at 5,000 mg/m^2.						

(U) Table A10: Standoff Distance for VX.

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Standoff Distance for VX						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	50	50	10	10	10
	100	50	50	10	10	10
	1,000	50	50	10	10	10
Severe						
	10	100	50	10	10	10
	100	100	50	10	10	10
	1,000	100	50	10	10	10
Mild						
	10	> 500	> 500	500	500	500
	100	> 500	> 500	500	500	500
	1,000	> 500	> 500	500	500	250
*Results for approximately three hours after contamination at 5,000 mg/m^2.						

(U) Table A11: Standoff Distance for 50, 500, and 5,000 mg/m^2.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	50	25	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	100	25	10	10	10
	VX	100	25	10	10	10
Mild						
	GD	100	50	10	10	10
	HD	100	25	10	10	10
	VX	> 500	500	250	250	100
*Results for approximately three hours after all three contamination densities.						

(U) Table A12: Standoff Distance 50, 500, and 5,000 mg/m^2.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	GD	250	100	50	10	10
	HD	10	10	10	10	10
	VX	100	50	10	10	10
Severe						
	GD	500	250	50	25	10
	HD	250	250	50	10	10
	VX	100	50	10	10	10
Mild						
	GD	> 500	> 500	> 500	500	250
	HD	250	250	50	10	10
	VX	> 500	> 500	500	500	250
*Results for approximately one hour after all three contamination densities.						

(U) Table A13: Standoff Distance 50, 500, and 5,000 mg/m^2.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	25	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	25	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	500	250	100	25	10
*Results for approximately 24 hours after all three contamination densities.						

(U) Table A14: Standoff Distance at One Hour After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	500	250	100	50	50
	HD	25	10	10	10	10
	VX	100	100	50	10	10
Severe						
	GD	500	500	250	100	50
	HD	500	250	100	50	25
	VX	250	100	50	25	10
Mild						
	GD	> 500	> 500	> 500	> 500	500
	HD	500	250	100	50	25
	VX	>500	> 500	> 500	> 500	500
*Results for approximately one hour after contamination at 5,000 mg/m^2.						

(U) Table A15: Standoff Distance at Three Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	50	50	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	100	50	10	10	10
	VX	100	50	10	10	10
Mild						
	GD	100	100	25	10	10
	HD	100	50	10	10	10
	VX	> 500	> 500	500	500	250
*Results for approximately three hours after contamination at 5,000 mg/m^2. The mean area covered results were identical for the three-hour results.						

(U) Table A16: Standoff Distance at 24 Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	25	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	500	250	100	25	10
*Results for approximately 24-hours after contamination at 5,000 mg/m^2.						

Appendix B
Parametric Results for 500 mg/m^2 Contamination Density

This annex provides the parametric results for the 500 mg/m^2 contamination density by aircraft, agent, time after contamination, standoff distance, relative wind angles, PSCs, and wind speeds.

(U) Table B1: Parametric Results By Aircraft.

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Parametric Results by Aircraft						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Aircraft	Lethal	Severe	Mild	Lethal	Severe	Mild
Fighter/Attack						
A-10	0.3 4.9	0.6 9.6	43.4 254.9	99.3	98.6	87.3
F-15	0.1 1.5	0.2 3.3	34.8 241.1	99.6	99.3	90.5
F-16	0.0 1.2	0.1 2.1	26.5 191.5	99.6	99.4	90.7
FA-22	0.1 2.8	0.4 6.4	40.5 257.9	99.4	98.9	89.2
F-35	0.0 0.0	0.0 0.0	49.8 292.0	100.0	100.0	88.2
F-117	0.4 7.2	0.9 14.0	54.3 304.1	99.2	98.5	86.7
Bomber						
B-1	0.7 18.3	1.6 38.5	155.0 769.9	99.2	98.7	85.7
B-2	4.7 69.6	10.5 138.8	292.6 1,088.8	98.7	97.6	79.8
B-52	0.1 3.6	0.7 20.7	111.9 722.7	99.7	99.5	91.0
Cargo/Tanker/Utility						
C-5	1.6 42.5	3.1 74.6	178.2 1,145.8	99.7	99.5	92.7
C-17	0.9 24.5	1.8 45.9	118.4 807.2	99.7	99.6	94.5
C-20	0.3 5.1	0.9 15.7	82.5 428.5	99.2	98.9	87.4
C-21	0.1 2.2	0.3 5.2	31.1 202.6	99.5	99.0	89.1
C-32	2.2 33.7	4.4 58.3	159.6 741.4	98.6	97.4	81.3
C-37	0.2 5.9	0.7 15.1	77.1 420.4	99.6	99.3	89.6
C-40	2.2 30.9	4.4 53.5	140.9 617.8	98.3	96.8	80.6

C-130	0.4 7.2	1.0 18.1	79.4 492.8	99.1	98.5	87.6
C-130J30	0.8 16.4	1.8 32.5	91.7 544.8	98.8	97.8	86.3
C-141	0.4 11.0	1.3 34.2	121.9 751.9	99.7	99.5	90.7
KC-10	0.7 20.8	1.6 44.1	145.9 867.8	99.8	99.7	92.2
KC-135	0.3 5.9	1.0 23.5	113.6 653.0	99.2	98.7	87.3
U-2	0.7 10.4	1.5 19.9	70.5 366.7	98.7	97.5	84.1
E-3	0.3 6.6	1.0 23.0	117.6 661.5	99.3	98.7	87.1
E-4	1.3 36.6	2.7 64.8	198.1 1,156.4	99.7	99.5	91.2
E-8	0.5 10.6	1.4 31.9	140.8 764.7	99.2	98.6	86.3
OC-135	0.3 6.1	1.0 23.0	112.6 658.9	99.3	98.8	87.5
RC-135	0.3 6.1	1.0 23.0	112.6 658.9	99.3	98.8	87.5
UAV						
MQ-1	0.0 0.0	0.0 0.0	7.5 76.4	100.0	100.0	96.9
RQ-4	0.6 7.9	1.3 14.2	52.1 289.1	98.5	97.1	83.1
Helicopter						
UH-1	0.0 0.0	0.0 0.0	0.0 0.0	100.0	100.0	100.0
MH-53	0.0 0.8	0.1 2.1	31.6 243.7	99.9	99.6	93.0
HH-60	0.0 0.3	0.1 2.4	31.3 225.8	99.8	99.6	92.7
Trainer						
T-1	0.1 2.5	0.3 5.8	37.3 232.0	99.5	99.2	89.4
T-6	0.0 0.7	0.1 1.2	13.2 108.8	99.3	98.7	90.4
T-37	0.0 0.1	0.0 0.5	13.8 112.4	99.9	99.7	93.8
T-38	0.0 0.0	0.0 0.0	4.2 49.5	100.0	100.0	98.5
T-43	0.2 3.8	0.7 12.4	68.4 427.6	99.3	98.8	87.9
500 mg/m^2 contamination density.						

(U) Table B2: Parametric Results By Agent.

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Parametric Results by Agent						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Agent	Lethal	Severe	Mild	Lethal	Severe	Mild
t-GD	1.7 31.9	3.9 62.7	227.7 958.9	98.2	97.3	80.3
HD	0.0 0.0	0.1 1.9	0.1 1.9	100.0	99.4	99.4
VX, t-VX	0.0 0.0	0.0 0.1	28.5 208.7	100.0	100.0	87.7
500 mg/m^2 contamination density.						

(U) Table B3: Parametric Results By Six Times After Contamination.

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Parametric Results by Time after Contamination						
Time (hour)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0.5	3.3 45.0	7.8 88.6	440.0 1,314.5	96.5	94.1	66.9
1	0.0 0.4	0.0 0.8	52.5 288.3	99.9	99.6	82.2
2	0.0 0.2	0.0 0.5	18.7 153.4	99.9	99.7	89.5
4	0.0 0.0	0.0 0.0	0.8 11.9	100.0	100.0	98.0
8	0.0 0.0	0.0 0.0	0.5 8.3	100.0	100.0	98.3
24	0.0 0.0	0.0 0.0	0.0 0.5	100.0	100.0	99.8
500 mg/m^2 contamination density.						

(U) Table B4: Parametric Results By Six Standoff Distances.

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Parametric Results by Standoff Distance						
Standoff distance (feet)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
10	1.2 24.3	2.6 47.2	135.2 726.4	98.1	96.6	76.2
25	0.9 22.9	2.1 45.1	124.8 701.9	99.0	98.2	83.0
50	0.7 21.2	1.6 42.2	112.0 667.7	99.5	99.1	87.9
100	0.4 18.4	1.1 36.8	91.0 597.7	99.8	99.6	92.2
250	0.1 11.0	0.4 22.1	44.6 383.2	100.0	99.9	96.4
500	0.0 2.2	0.0 4.3	5.0 69.0	100.0	100.0	99.0
500 mg/m^2 contamination density.						

(U) Table B5: Parametric Results By Nine Relative Wind Angles.

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Parametric Results by Relative Wind Angle						
Angle (degree)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0	2.1 43.5	5.1 86.1	172.5 806.0	99.1	98.6	85.0
30	0.3 10.9	0.6 22.0	87.7 597.6	99.6	99.2	90.5
45	0.3 11.8	0.6 22.5	79.4 564.1	99.5	99.2	90.6
60	0.3 11.9	0.7 23.7	77.8 563.1	99.5	99.2	90.5
90	0.9 19.7	2.1 35.2	151.2 35.2	98.6	97.5	83.7
120	0.3 10.2	0.6 18.0	56.5 375.9	99.6	99.2	90.8
135	0.3 10.0	0.6 18.5	51.8 329.2	99.5	99.1	90.6
150	0.3 9.8	0.6 18.9	48.2 290.4	99.5	99.2	90.5
180	0.3 8.4	0.8 24.6	43.7 257.3	99.5	99.1	89.8
500 mg/m^2 contamination density.						

(U) Table B6: Parametric Results By Pasquill Stability Category.

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Parametric Results by Pasquill Stability Category						
Pasquill Stability Category	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
A	0.0 1.6	0.1 3.4	26.6 284.0	99.8	99.7	94.7
B	0.1 3.2	0.2 7.3	48.5 453.9	99.7	99.5	92.8
C	0.2 5.9	0.5 13.4	71.4 575.0	99.6	99.2	90.3
D	0.4 9.5	0.9 21.0	90.7 631.0	99.4	98.8	88.3
E	0.8 19.9	2.1 44.5	124.7 698.1	99.1	98.4	85.8
F	1.8 38.7	4.1 72.3	150.5 688.5	98.8	97.8	82.9
500 mg/m^2 contamination density.						

(U) Table B7: Parametric Results By Three Windspeeds.

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Parametric Results by Windspeed						
Windspeed (m/sec)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
1	1.6 31.8	3.7 62.6	176.4 883.7	98.6	97.7	82.8
3	0.0 1.5	0.2 4.2	54.1 380.6	99.6	99.3	90.9
5	0.0 0.5	0.0 1.1	25.8 235.1	99.9	99.7	93.7
500 mg/m^2 contamination density.						

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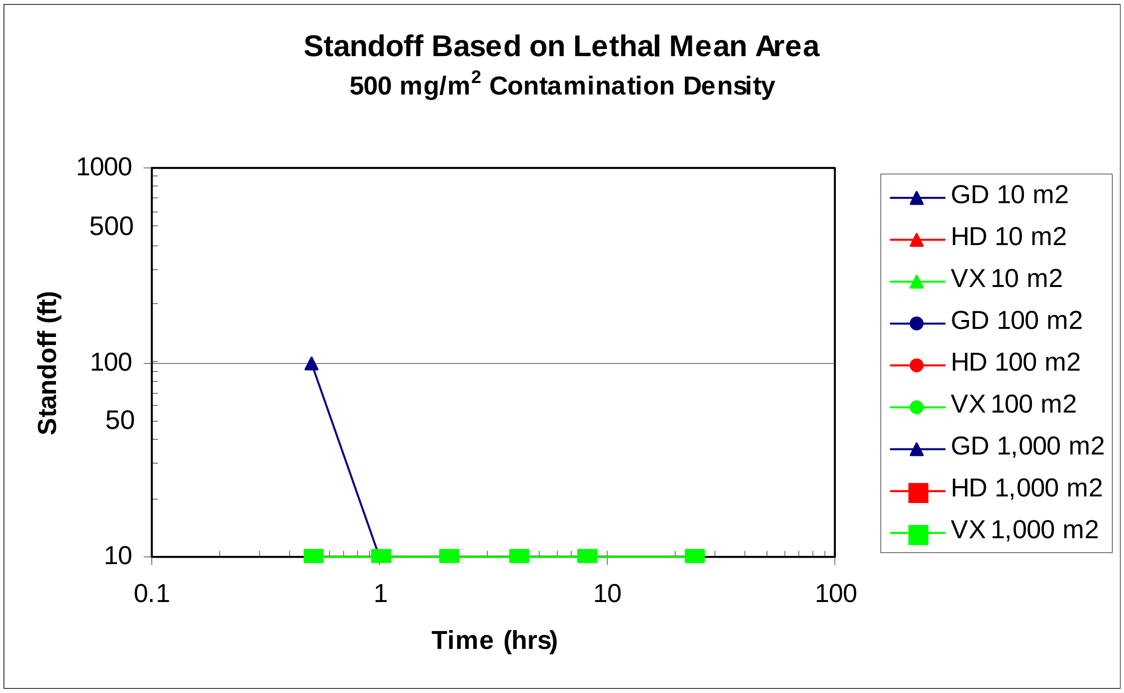

(U) Figure B1: Standoff Distance Based on Lethal Mean Area.

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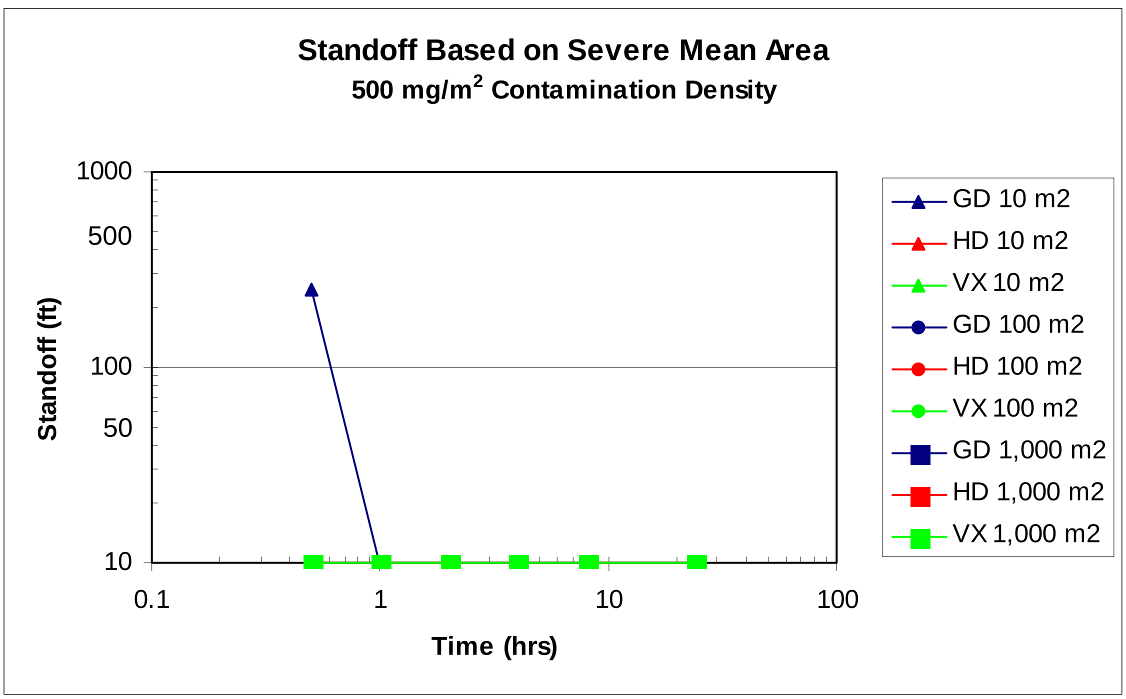

(U) Figure B2: Standoff Distance Based on Severe Mean Area.

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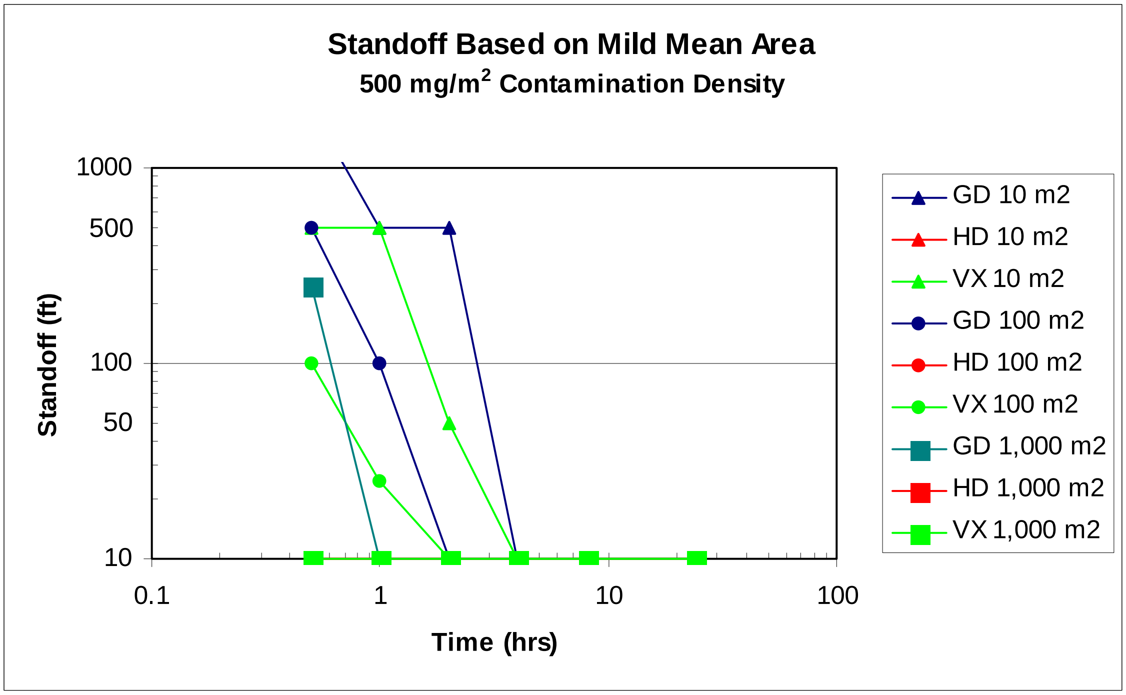

(U) Figure B3: Standoff Distance Based on Mild Mean Area.

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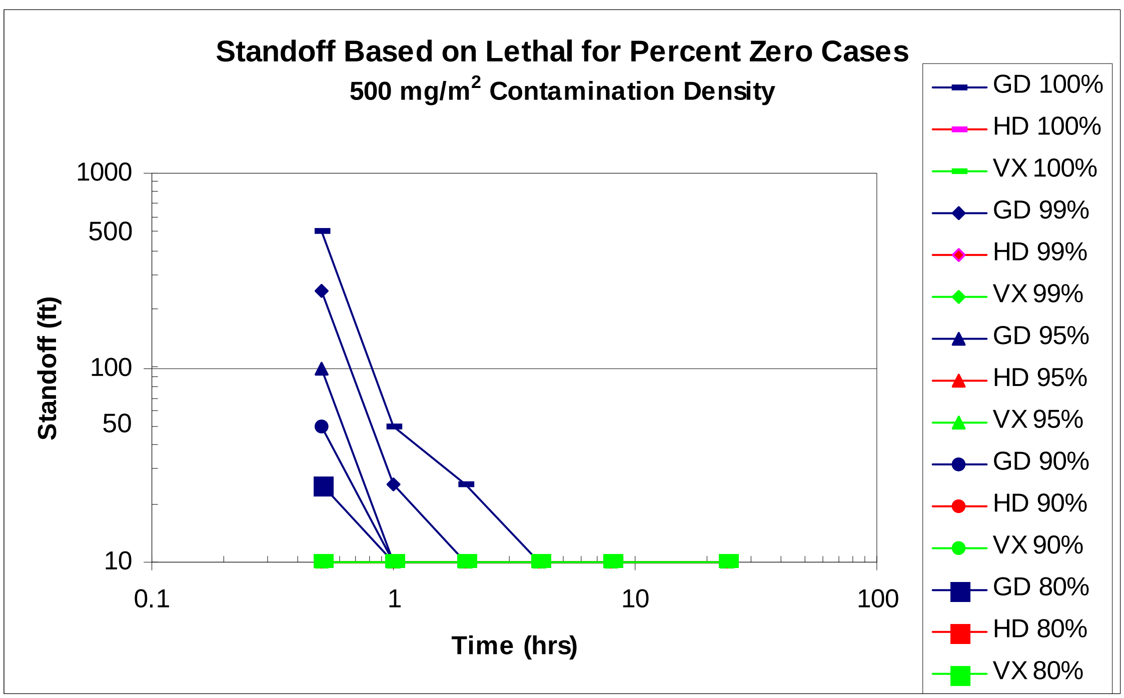

(U) Figure B4: Standoff Distance Based on Lethal for Percent Zero Cases.

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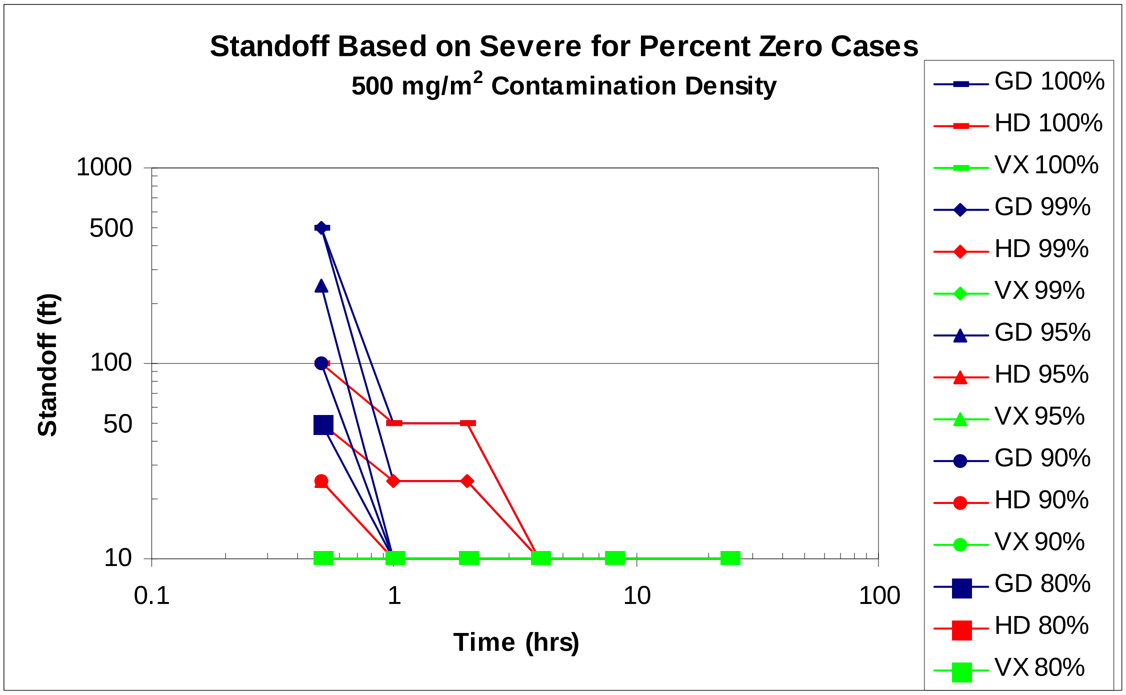
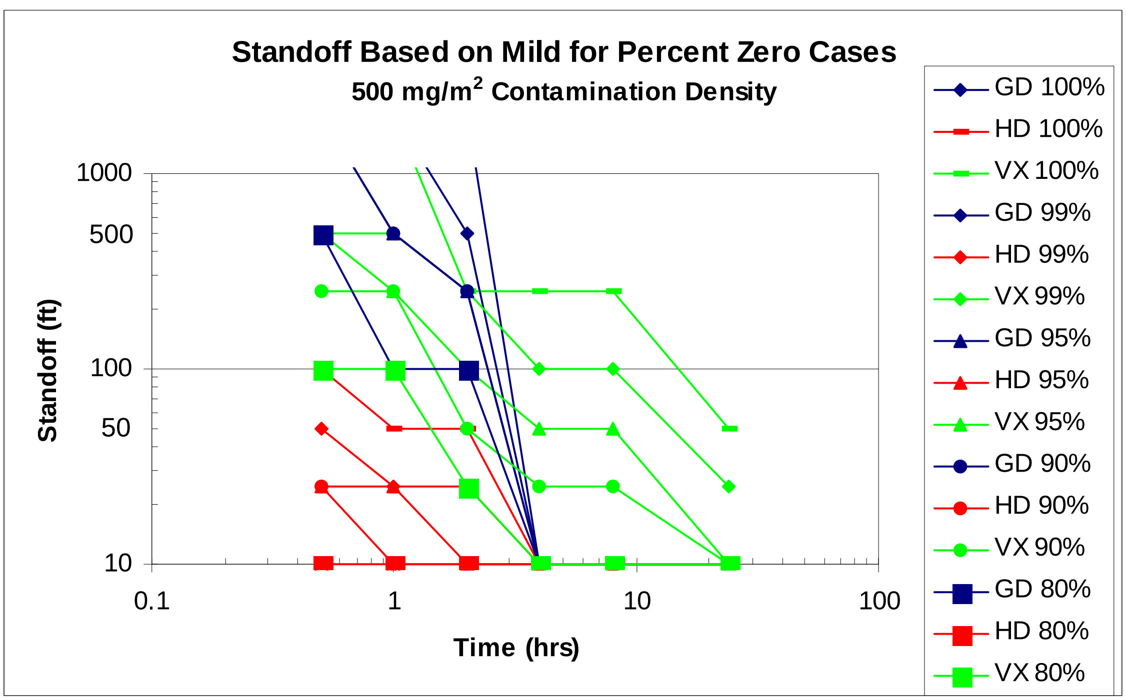


(U) Figure B5: Standoff Distance Based on Severe for Percent Zero Cases.

UNCLASSIFIED



(U) Figure B6: Standoff Distance Based on Mild for Percent Zero Cases.

(U) Table B8: Standoff Distance for GD.

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Standoff Distance for GD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
*Results for approximately three hours after contamination at 500 mg/m^2.						

(U) Table B9: Standoff Distance for HD.

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Standoff Distance for HD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
*Results for approximately three hours after contamination at 500 mg/m^2.						

(U) Table B10: Standoff Distance for VX.

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Standoff Distance for VX						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	250	100	50	25	10
	100	250	100	50	25	10
	1,000	250	100	50	25	10
*Results for approximately three hours after contamination at 500 mg/m^2.						

(U) Table B11: Standoff Distance One Hour After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	50	25	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	50	25	10	10	10
	HD	50	25	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	> 500	500	500	250	100
	HD	50	25	10	10	10
	VX	> 500	500	250	250	100
*Results for approximately one hour after contamination at 500 mg/m^2.						

(U) Table B12: Standoff Distance Three Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	250	100	50	25	10
*Results for approximately three hours after contamination at 500 mg/m^2. The mean area covered results were identical for the three-hour results.						

(U) Table B13: Standoff Distance 24 Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	50	25	10	10	10
*Results for approximately 24-hours after contamination at 500 mg/m^2.						

Appendix C
Parametric Results for 50 mg/m² Contamination Density

This annex provides the parametric results for the 50 mg/m² contamination density by aircraft, agent, time after contamination, standoff distance, relative wind angles, PSCs, and wind speeds.

(U) Table C1: Parametric Results By Aircraft.

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Parametric Results by Aircraft						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Aircraft	Lethal	Severe	Mild	Lethal	Severe	Mild
Fighter/Attack						
A-10	0.00 0.06	0.00 0.12	3.59 38.47	99.95	99.92	96.43
F-15	0.00 0.01	0.00 0.07	1.36 19.93	99.99	99.98	98.01
F-16	0.00 0.00	0.00 0.00	0.97 13.88	100.00	100.00	98.13
FA-22	0.00 0.03	0.00 0.08	2.15 26.94	99.98	99.97	97.00
F-35	0.00 0.01	0.00 0.03	3.29 37.36	99.99	99.97	96.52
F-117	0.00 0.04	0.00 0.10	4.27 45.63	99.96	99.90	96.11
Bomber						
B-1	0.00 0.09	0.00 0.16	9.88 115.67	99.97	99.94	96.38
B-2	0.00 0.00	0.00 0.04	23.64 241.63	100.00	99.98	95.96
B-52	0.00 0.00	0.00 0.00	4.53 76.15	100.00	100.00	98.39
Cargo/Tanker/Utility						
C-5	0.00 0.00	0.00 0.00	9.53 162.99	100.00	100.00	98.81
C-17	0.00 0.00	0.00 0.00	5.75 106.10	100.00	100.00	99.18
C-20	0.00 0.05	0.00 0.19	5.15 62.53	99.97	99.94	96.90
C-21	0.00 0.00	0.00 0.05	2.18 23.00	100.00	99.97	97.19
C-32	0.00 0.20	0.01 0.33	12.74 134.58	99.95	99.85	95.20
C-37	0.00 0.00	0.00 0.00	3.78 50.30	100.00	100.00	98.59
C-40	0.00 0.21	0.01 0.44	11.66 117.91	99.94	99.83	94.94
C-130	0.01 0.34	0.01 0.54	3.54 53.09	99.95	99.93	96.88
C-130J-30	0.01 0.35	0.02 0.88	5.46 74.16	99.86	99.75	95.95

C-141	0.00 0.00	0.00 0.00	5.42 89.28	100.00	100.00	98.50
KC-10	0.00 0.00	0.00 0.00	6.00 103.85	100.00	100.00	98.82
KC-135	0.00 0.08	0.00 0.14	4.61 69.84	99.97	99.95	97.07
U-2	0.00 0.14	0.01 0.33	4.62 53.88	99.95	99.85	96.29
E-3	0.00 0.10	0.00 0.16	5.09 73.95	99.97	99.95	96.95
E-4	0.00 0.00	0.00 0.00	8.70 151.73	100.00	100.00	98.79
E-8	0.00 0.10	0.00 0.16	6.87 91.06	99.97	99.92	96.43
OC-135	0.00 0.06	0.00 0.13	5.11 71.17	99.98	99.94	96.71
RC-135	0.00 0.06	0.00 0.13	5.11 71.17	99.98	99.94	96.71
UAV						
MQ-1	0.00 0.00	0.00 0.00	0.00 0.09	100.00	100.00	99.98
RQ-4	0.00 0.06	0.01 0.32	2.67 28.83	99.94	99.83	96.25
Helicopter						
UH-1	0.00 0.00	0.00 0.00	0.00 0.02	100.00	100.00	99.99
MH-53	0.00 0.00	0.00 0.00	1.13 18.84	100.00	100.00	98.86
HH-60	0.00 0.00	0.00 0.00	0.99 16.16	100.00	100.00	98.91
Trainer						
T-1	0.00 0.00	0.00 0.00	1.71 23.39	100.00	100.00	97.95
T-6	0.00 0.03	0.00 0.06	0.24 3.45	99.95	99.93	98.18
T-37	0.00 0.00	0.00 0.00	0.23 4.01	100.00	100.00	99.21
T-38	0.00 0.00	0.00 0.00	0.00 0.00	100.00	100.00	100.00
T-43	0.00 0.00	0.00 0.09	3.48 45.94	100.00	99.96	96.63
50 mg/m^2 contamination density.						

(U) Table C2: Parametric Results By Three Agents.

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Parametric Results by Agent						
	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
Agent	Lethal	Severe	Mild	Lethal	Severe	Mild
t-GD	0.00 0.177	0.01 0.377	13.56 140.610	99.95	99.88	94.34
HD	0.00 0.000	0.00 0.041	0.00 0.041	100.00	99.99	99.99
VX, t-VX	0.00 0.021	0.00 0.041	0.77 0.041	99.99	99.98	98.14
50 mg/m^2 contamination density.						

(U) Table C3: Parametric Results By Six Times After Contamination.

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Parametric Results by Time after Contamination						
Time (hour)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0.5	0.01 0.251	0.02 0.538	27.73 198.463	99.88	99.73	88.89
1	0.00 0.015	0.00 0.040	0.68 10.784	99.99	99.98	97.57
2	0.00 0.000	0.00 0.009	0.14 2.743	100.00	100.00	99.05
4	0.00 0.000	0.00 0.000	0.05 1.557	100.00	100.00	99.77
8	0.00 0.000	0.00 0.000	0.04 1.344	100.00	100.00	99.79
24	0.00 0.000	0.00 0.000	0.01 0.319	100.00	100.00	99.90
50 mg/m^2 contamination density.						

(U) Table C4: Parametric Results By Six Standoff Distances.

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Parametric Results by Standoff Distance						
Standoff distance (feet)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
10	0.00 0.198	0.01 0.406	9.28 106.986	99.91	99.78	92.67
25	0.00 0.142	0.00 0.302	7.59 101.722	99.97	99.94	95.84
50	0.00 0.062	0.00 0.185	5.95 94.591	99.99	99.98	97.80
100	0.00	0.00	4.07	100.00	100.00	98.98

	0.000	0.018	81.753			
250	0.00 0.000	0.00 0.000	1.58 50.567	100.00	100.00	99.72
500	0.00 0.000	0.00 0.000	0.18 10.269	100.00	100.00	99.95
50 mg/m^2 contamination density.						

(U) Table C5: Parametric Results By Nine Relative Wind Angles.

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Parametric Results by Relative Wind Angle						
Angle (degree)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
0	0.00 0.007	0.00 0.064	15.14 178.351	100.00	99.99	96.94
30	0.00 0.004	0.00 0.049	3.01 60.442	100.00	99.99	98.17
45	0.00 0.044	0.00 0.090	2.66 55.034	99.99	99.98	98.15
60	0.00 0.043	0.00 0.102	2.58 53.014	99.99	99.98	98.12
90	0.01 0.298	0.02 0.617	7.58 98.614	99.87	99.76	95.36
120	0.00 0.019	0.00 0.079	2.68 45.031	99.99	99.97	97.70
135	0.00 0.025	0.00 0.079	2.81 45.640	99.99	99.97	97.67
150	0.00 0.016	0.00 0.074	3.05 48.945	99.99	99.97	97.77
180	0.00 0.031	0.00 0.114	3.46 50.494	99.99	99.95	97.55
50 mg/m^2 contamination density.						

(U) Table C6: Parametric Results By Six PSCs.

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Parametric Results by Pasquill Stability Category						
Pasquill Stability Category	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
A	0.00 0.003	0.00 0.012	1.00 17.159	100.00	99.99	98.56
B	0.00 0.011	0.00 0.026	1.14 23.629	99.99	99.98	98.60
C	0.00 0.036	0.00 0.069	2.33 41.841	99.98	99.96	97.95
D	0.00 0.043	0.00 0.080	3.45 62.974	99.99	99.96	97.47
E	0.00	0.00	7.44	99.97	99.92	96.73

	0.103	0.207	109.682			
F	0.00 0.223	0.01 0.486	13.29 146.405	99.95	99.89	95.65
50 mg/m^2 contamination density.						

(U) Table C7: Parametric Results By Three Windspeeds.

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Parametric Results by Windspeed						
Windspeed (m/sec)	Area Covered (m^2) (Mean/Standard Deviation)			Percent of Cases with Zero Area Covered		
	Lethal	Severe	Mild	Lethal	Severe	Mild
1	0.00 0.173	0.01 0.375	12.46 138.500	99.94	99.87	94.94
3	0.00 0.040	0.00 0.061	1.52 27.380	100.00	99.99	98.46
5	0.00 0.018	0.00 0.032	0.34 7.259	100.00	100.00	99.09
50 mg/m^2 contamination density.						

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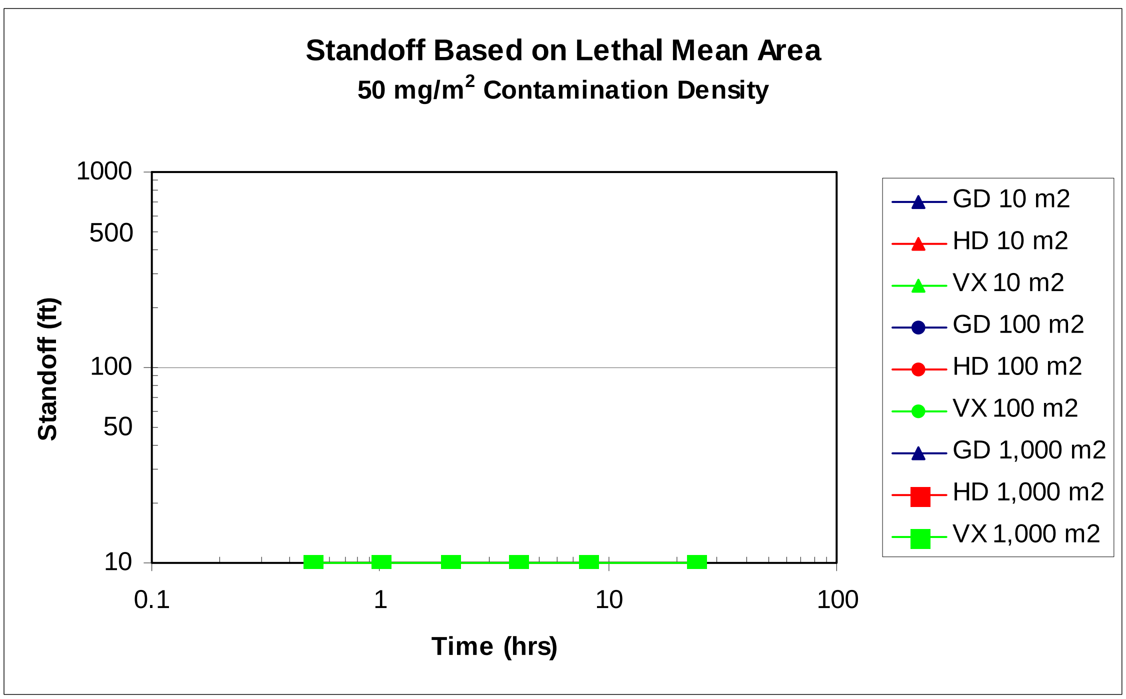

(U) Figure C1: Standoff Distance Based on Lethal Mean Area. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

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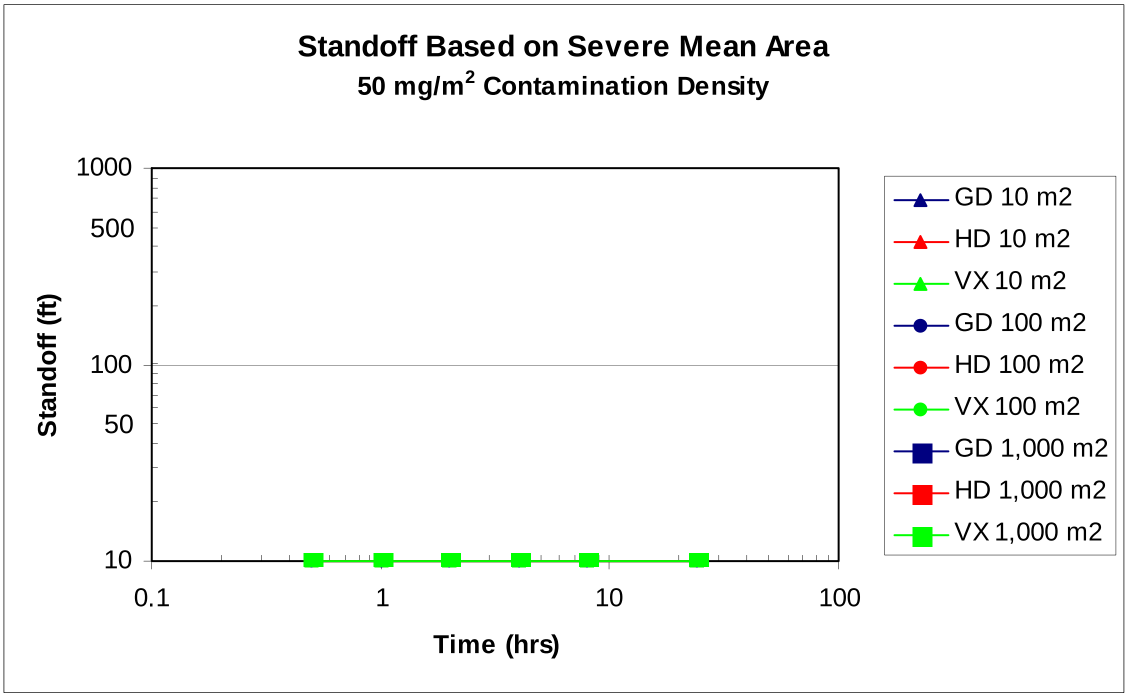
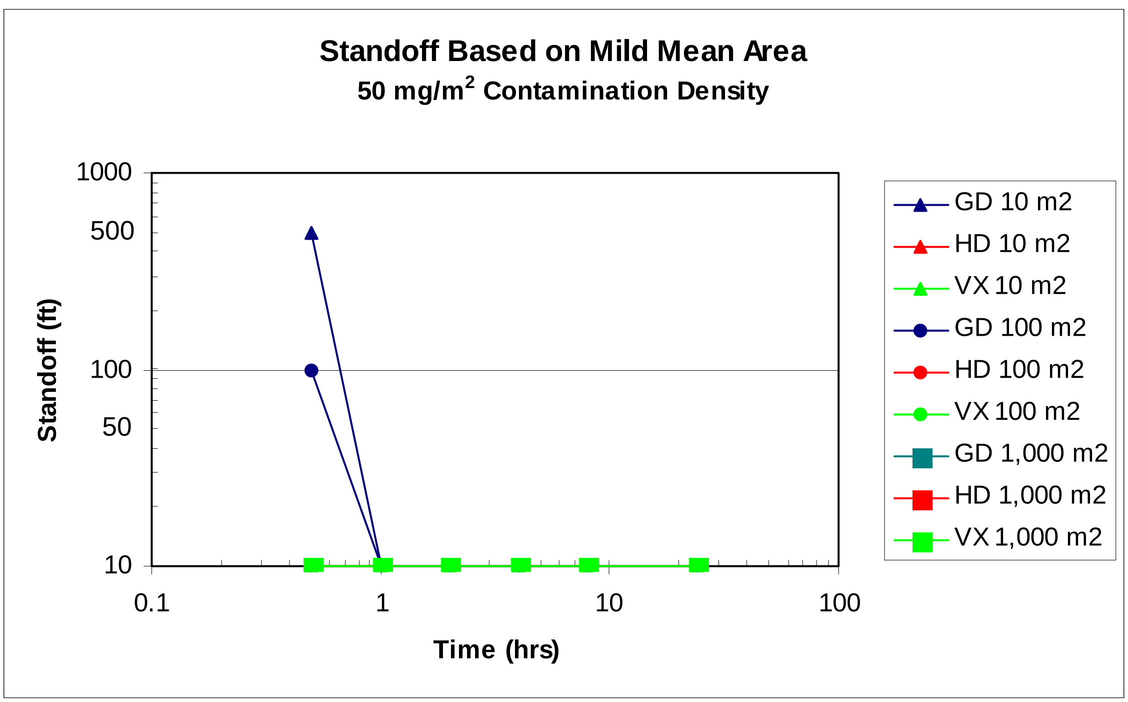


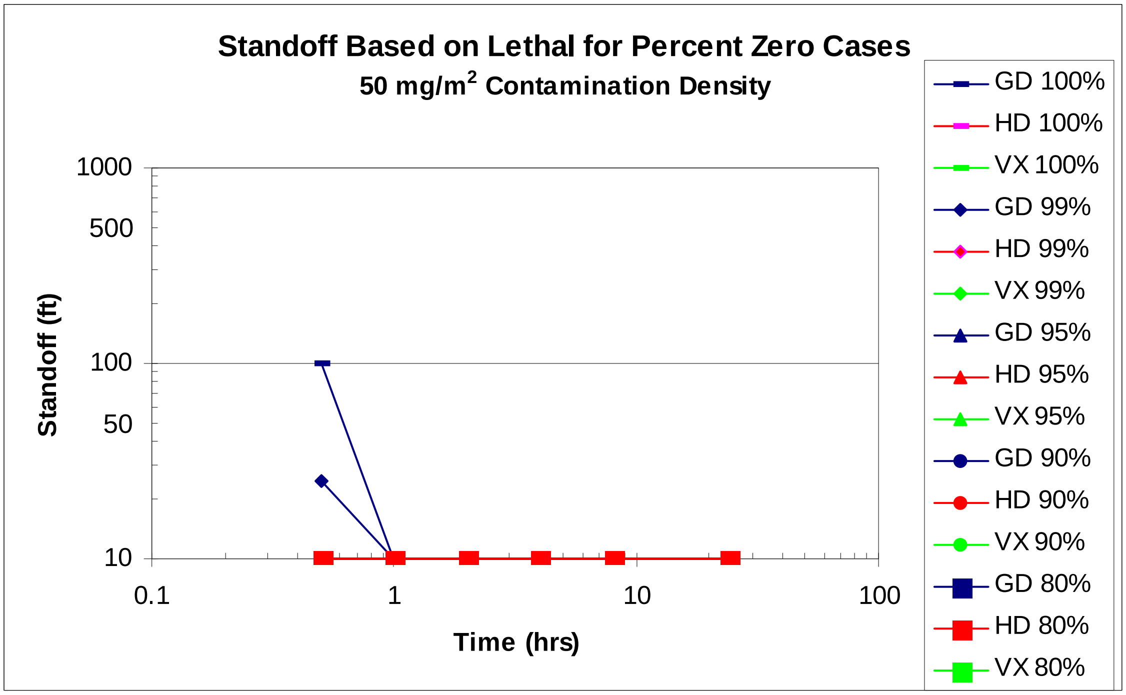
(U) Figure C2: Standoff Distance Based on Severe Mean Area. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

UNCLASSIFIED



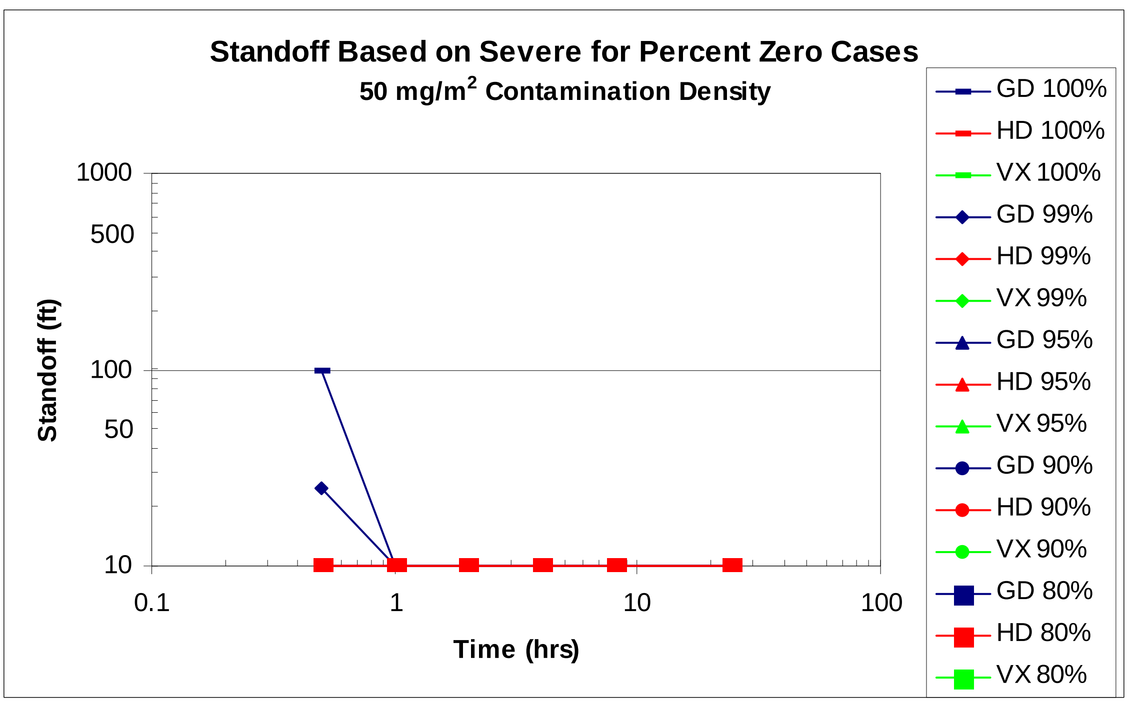
(U) Figure C3: Standoff Distance Based on Mild Mean Area. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

UNCLASSIFIED



(U) Figure C4: Standoff Distance Based on Lethal for Percent Zero Cases. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

UNCLASSIFIED



(U) Figure C5: Standoff Distance Based on Severe for Percent Zero Cases. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

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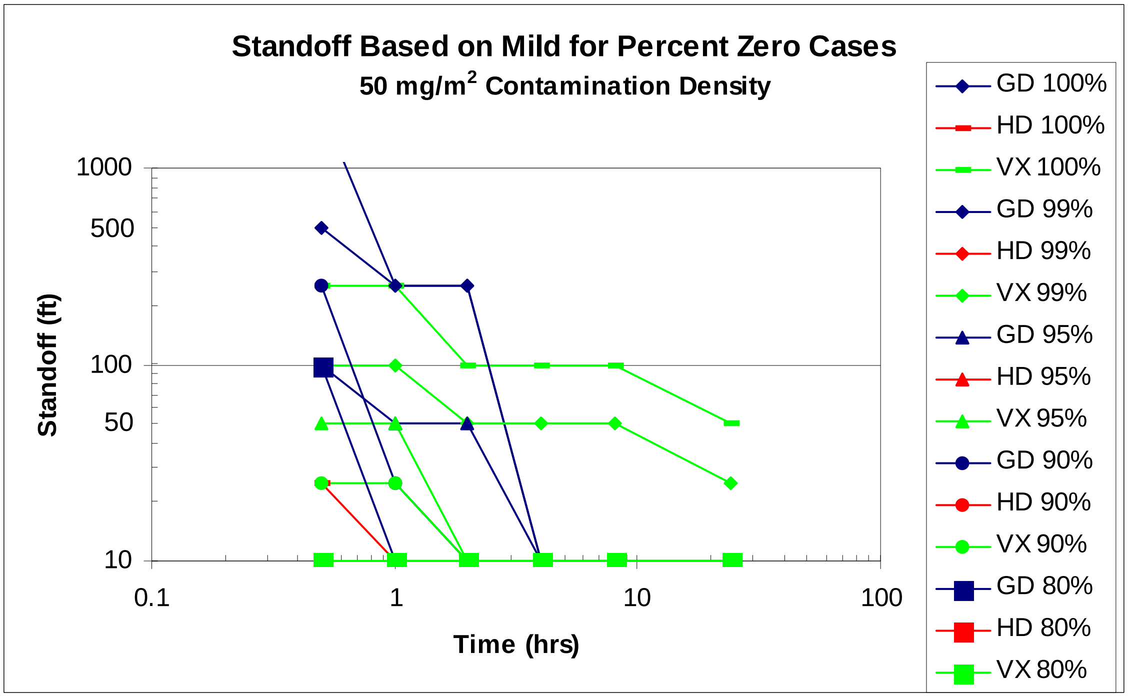

(U) Figure C6: Standoff Distance Based on Mild for Percent Zero Cases. It is important to note that many of the cases are stacked and not visible, but they satisfy the 10-foot rule.

(U) Table C8: Standoff Distance for GD Three Hours After Contamination.

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Standoff Distance for GD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
*Results for approximately three hours after contamination at 50 mg/m^2.						

(U) Table C9: Standoff Distance for HD at Three Hours After Contamination.

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Standoff Distance for HD						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
*Results for approximately three hours after contamination at 50 mg/m^2.						

(U) Table C10: Standoff Distance for VX at Three Hours After Contamination.

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Standoff Distance for VX						
		Percent of Zero Cases				
	Area Covered (m^2)	100	99	95	90	80
Lethal						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Severe						
	10	10	10	10	10	10
	100	10	10	10	10	10
	1,000	10	10	10	10	10
Mild						
	10	50	10	10	10	10
	100	50	10	10	10	10
	1,000	50	10	10	10	10
*Results for approximately three hours after contamination at 50 mg/m^2.						

(U) Table C11: Standoff Distance at One Hour After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	100	100	50	25	10
	HD	10	10	10	10	10
	VX	100	100	50	25	10
*Results for approximately one hour after contamination at 50 mg/m^2.						

(U) Table C12: Standoff Distance at Three Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	50	10	10	10	10
*Results for approximately three hours after contamination at 50 mg/m^2. The mean area covered results were identical for the three-hour results.						

(U) Table C13: Standoff Distance at 24 Hours After Contamination.

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Standoff Distance (feet)						
		Percent of Zero Cases				
	Agent	100	99	95	90	80
Lethal						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Severe						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	10	10	10	10	10
Mild						
	GD	10	10	10	10	10
	HD	10	10	10	10	10
	VX	25	10	10	10	10
*Results for approximately 24 hours after contamination at 50 mg/m^2.						

Appendix D
Use of M8 Detection Paper to Characterize Contamination Density

After a chemical attack, one of the initial response actions is to survey prepositioned M8 paper. The M8 paper shows the deposition of liquid agent from each munition system to confirm the location of the hazard pattern. The location of positive M8 paper results and the agent(s) detected are used in the base post-attack reconnaissance survey in order to identify the zones of the base that pose both a higher and a lesser risk to personnel. Vapor agent detectors can also be used to identify hazard areas. Current detector sensitivity is designed to identify severe incapacitation or lethal levels of concentration. Unfortunately, current generation vapor detectors are not sensitive enough to identify mild effects, which may occur over minutes to hours.

(U) Table D1: Time to Human Effects at Detector Alarm Sensitivity.

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Time to Human Effects at Detector Alarm Sensitivity (minutes)						
	GD		HD		VX	
Detector	Severe ICt16	Mild ECt16	Severe ICt16	Mild ECt16	Severe ICt16	Mild ECt16
Chemical Agent Monitor (CAM)[a,b,c]	165	9	116	116	17	2.2
Improved Chemical Agent Monitor (ICAM)[c]	165	9	116	116	17	2.2
M8A1[a,b]	25	1.4			4.3	0.55
M90[a,b,c]	25	1.4	58	58	85	11
Automatic Chemical Agent Alarm (ACADA)[b,c]	50	2.7	5.8	5.8	43	5.5
M256A1 Kit[a,b,c]	992	54	5.8	5.8	85	11

[a] Brletich, Nancy; Waters, Mary; Bowen, Gregory; and Tracy, Mary, *Worldwide Chemical Detection Equipment Handbook*, October 1995.
[b] U.S. Army Edgewood Chemical and Biological Center (ECBC), *Follow On Verification Test Report for the M22 Automatic Chemical Agent Alarm*, Edgewood Arsenal, MD, July 1999.
[c] Department of the Army, *Department of the Army Pamphlet (PAM) 385-61*, 28 March 2002.

Note: Table based on breathing rate of 60 liters/minute.

The Air Force has accepted the use of M8 paper as a key component in identifying the extent of a chemical attack and a key adjuvant to remedy limitations in the capabilities of vapor detectors.

The following figures present images of M8 paper at key locations relative to the location of a plume for a VX and then an HD attack. The droplet size and contamination density varies over the area covered by the liquid deposition footprint.

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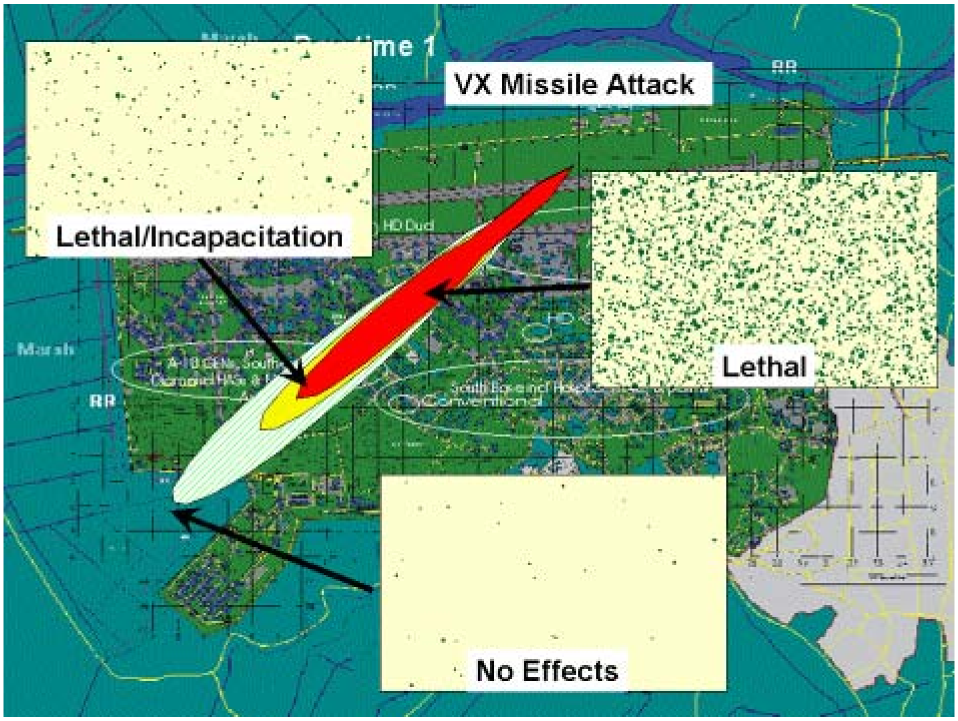

(U) Figure D1: M8 Paper at Key Locations Relative to the Location of the VX Plume.

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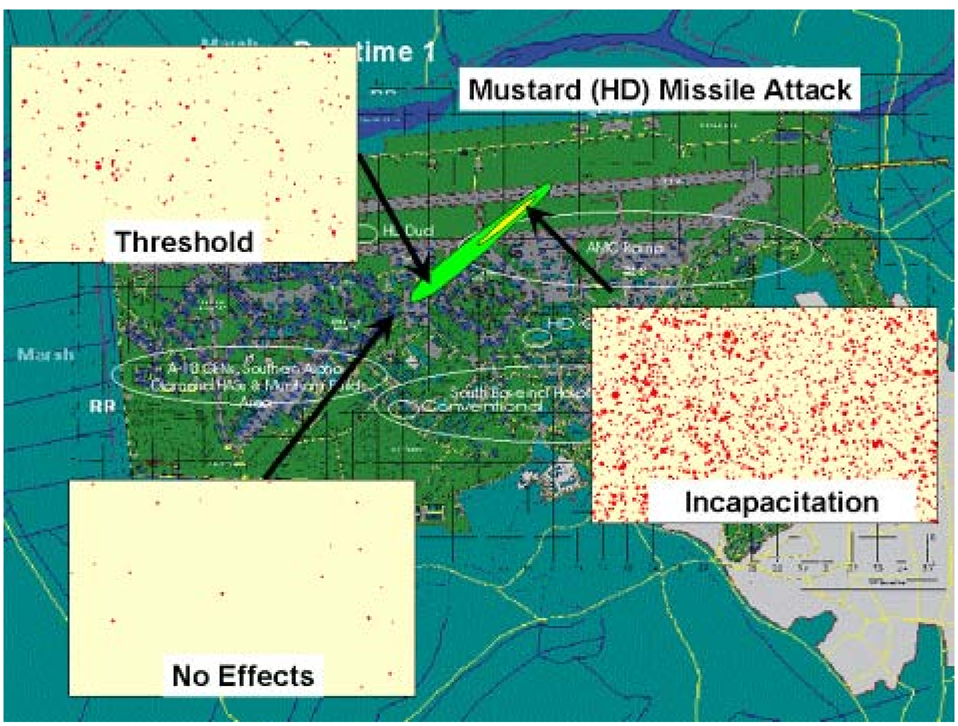

(U) Figure D2: M8 Paper at Key Locations Relative to the Location of the HD Plume.

The following 12 pages of images show the characteristic look of M8 paper contaminated at three different contamination densities (50, 500, and 5,000 mg/m^2), and four median droplet sizes (125, 250, 500, and 1000 microns). The color of the drops were done in black to aid visualization in this document, but agent contaminated paper would be consistent with the color map on the inside color of the M8 booklet, (e.g., G-agents are gold initially, H-agents are red, and V-agents are blue-green). The entire visible area of the page contains droplets to size, so different sections of the page that would be the size of actual M8 paper could have the differences in appearance represented by the much larger area of the page.

It is the author's conclusion in looking at these images, that it appears that a decision aid and training could be developed for the field that could help with determining the contamination density if M8 paper was placed on or close to a contaminated aircraft.

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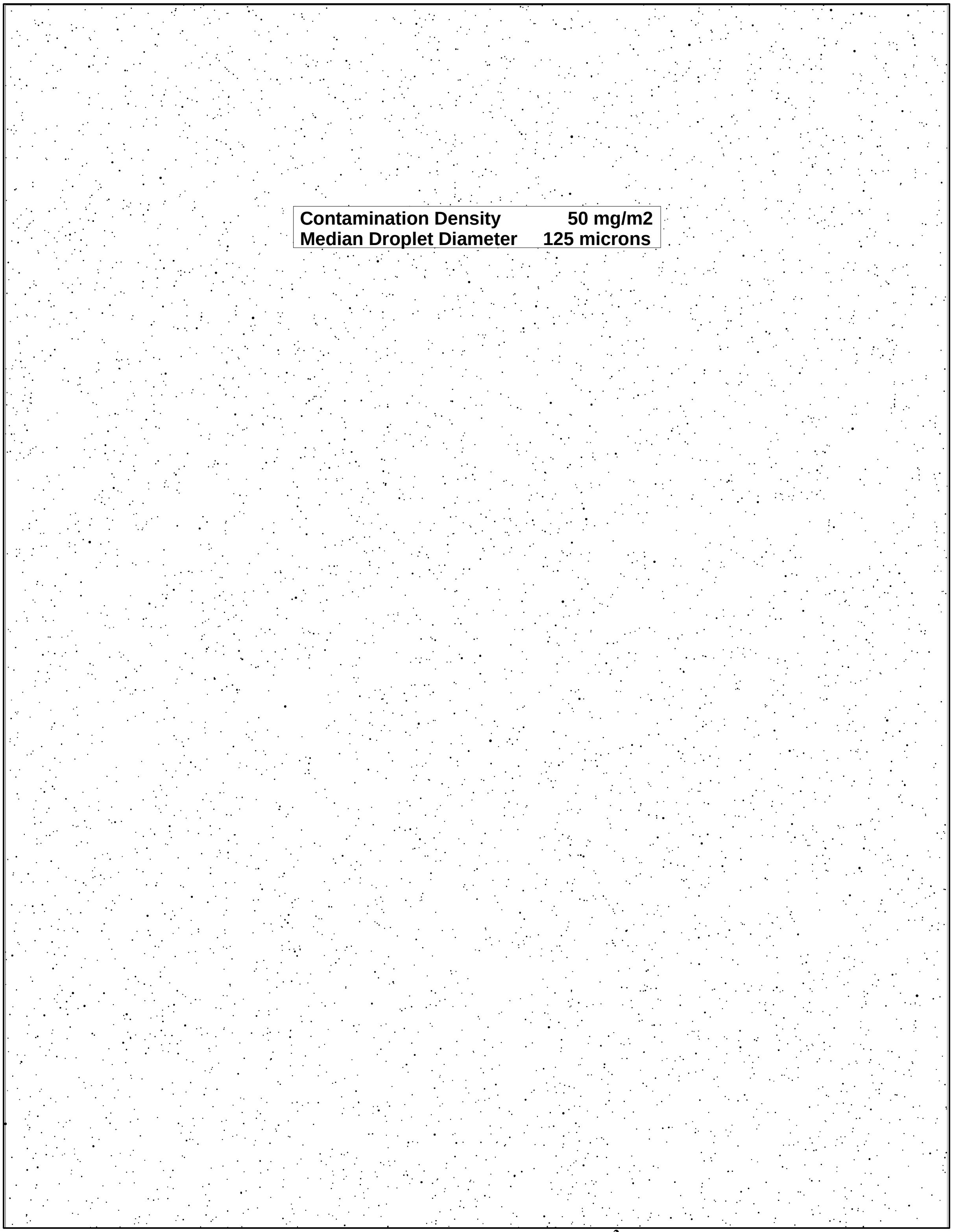

(U) Figure D3: M8 Paper with Contamination Density of 50 mg/m^2 and Median Droplet Diameter of 125 Microns.

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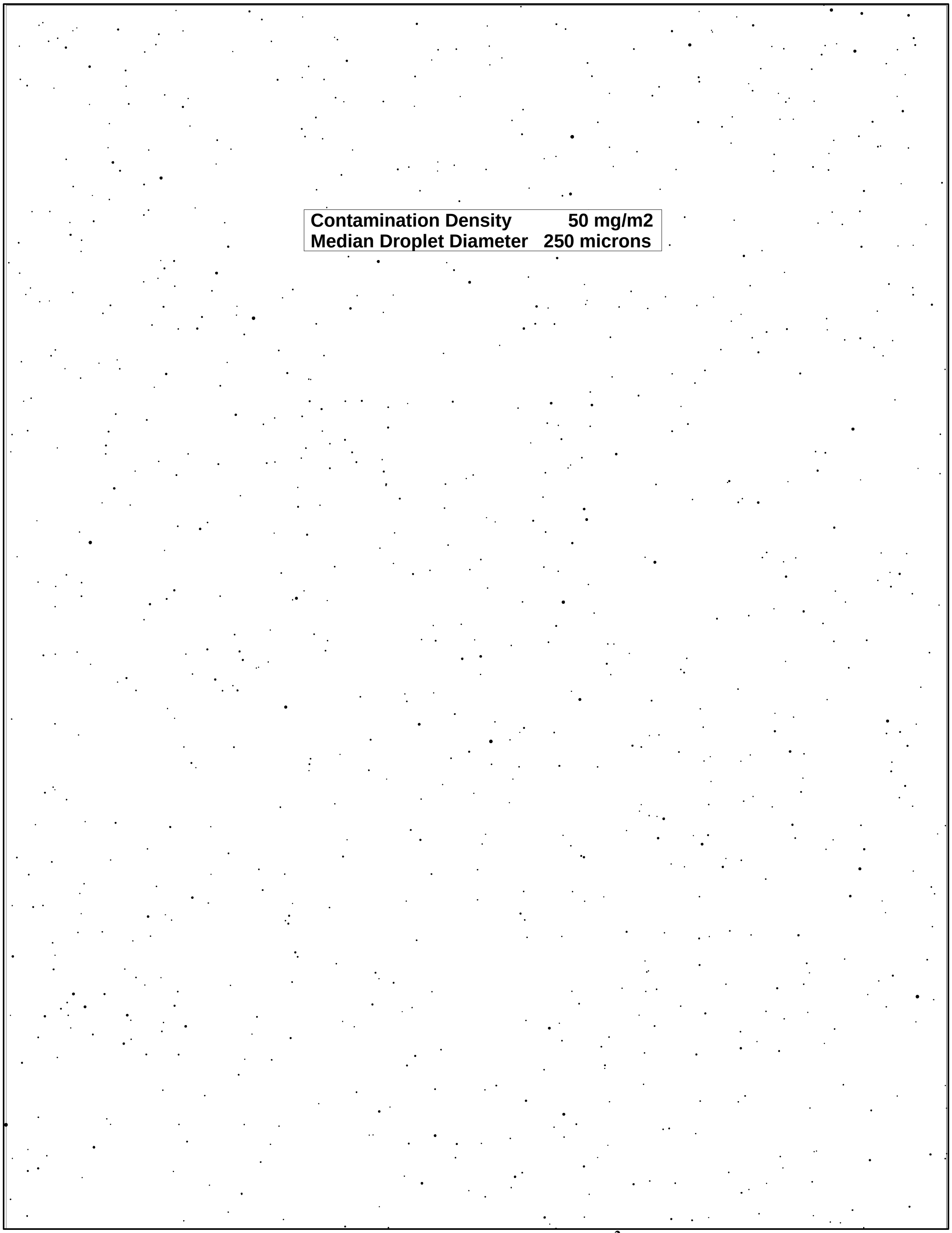

(U) Figure D4: M8 Paper with Contamination Density of 50 mg/m^2 and Median Droplet Diameter of 250 Microns.

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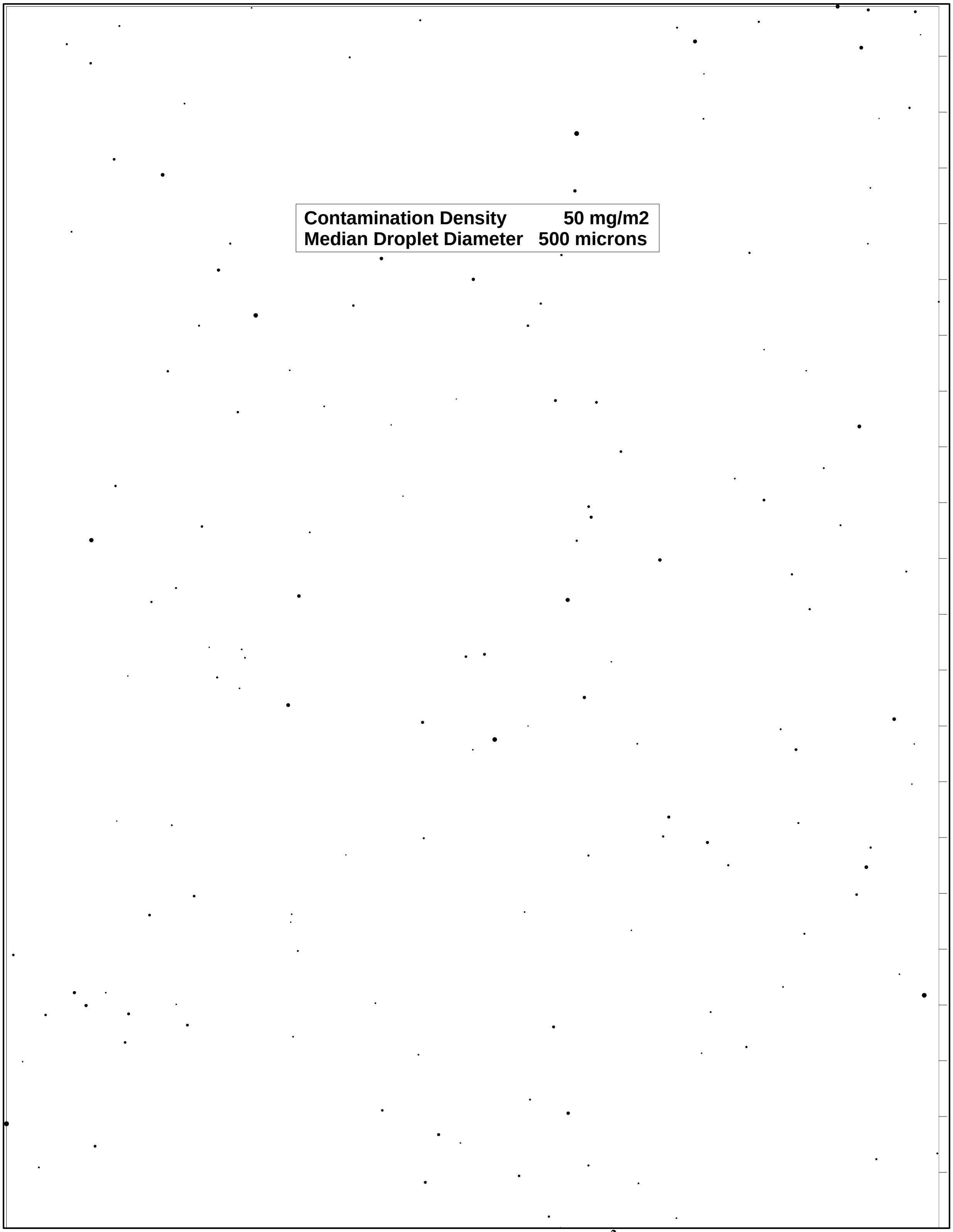

(U) Figure D5: M8 Paper with Contamination Density of 50 mg/m^2 and Median Droplet Diameter of 500 Microns.

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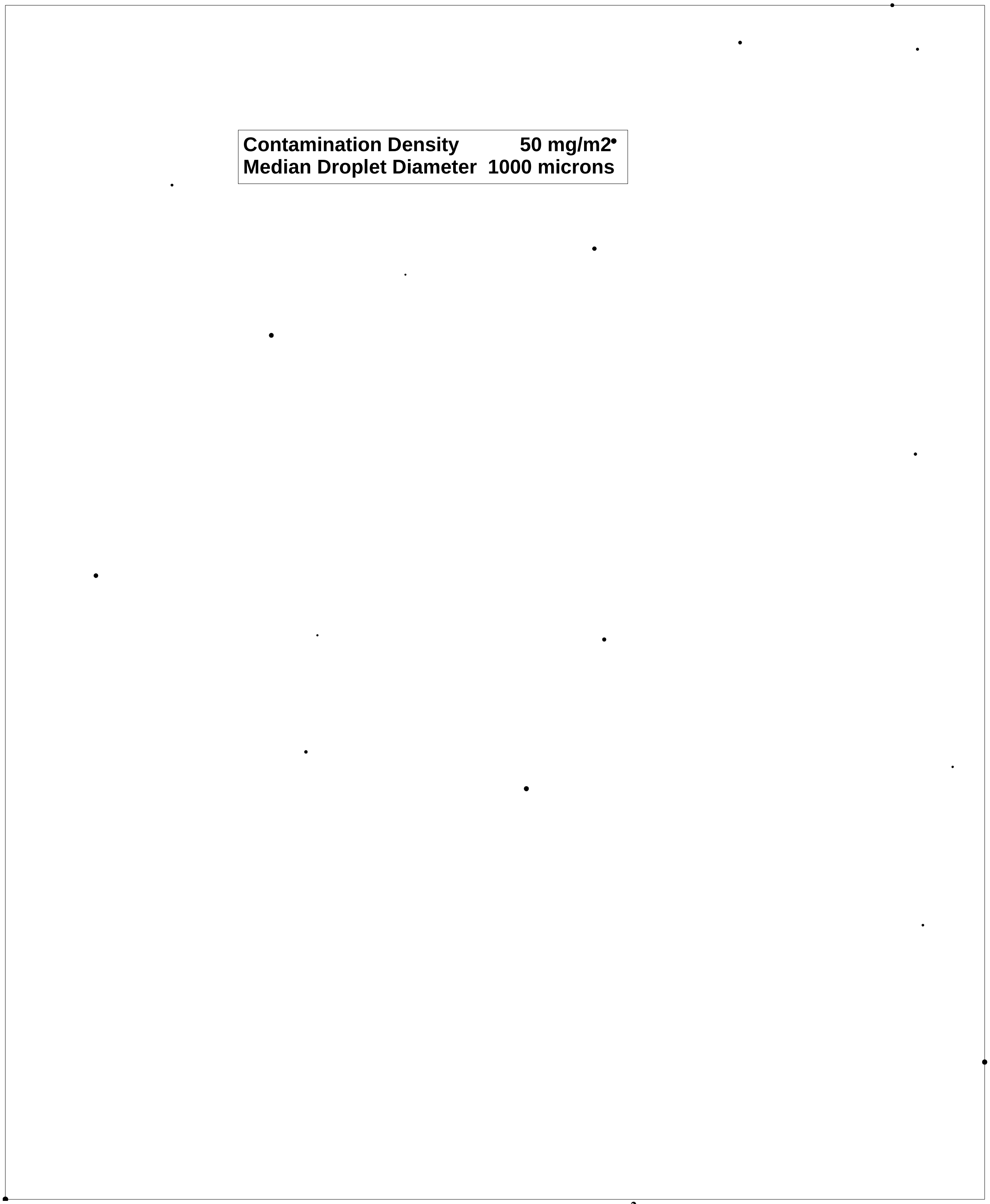
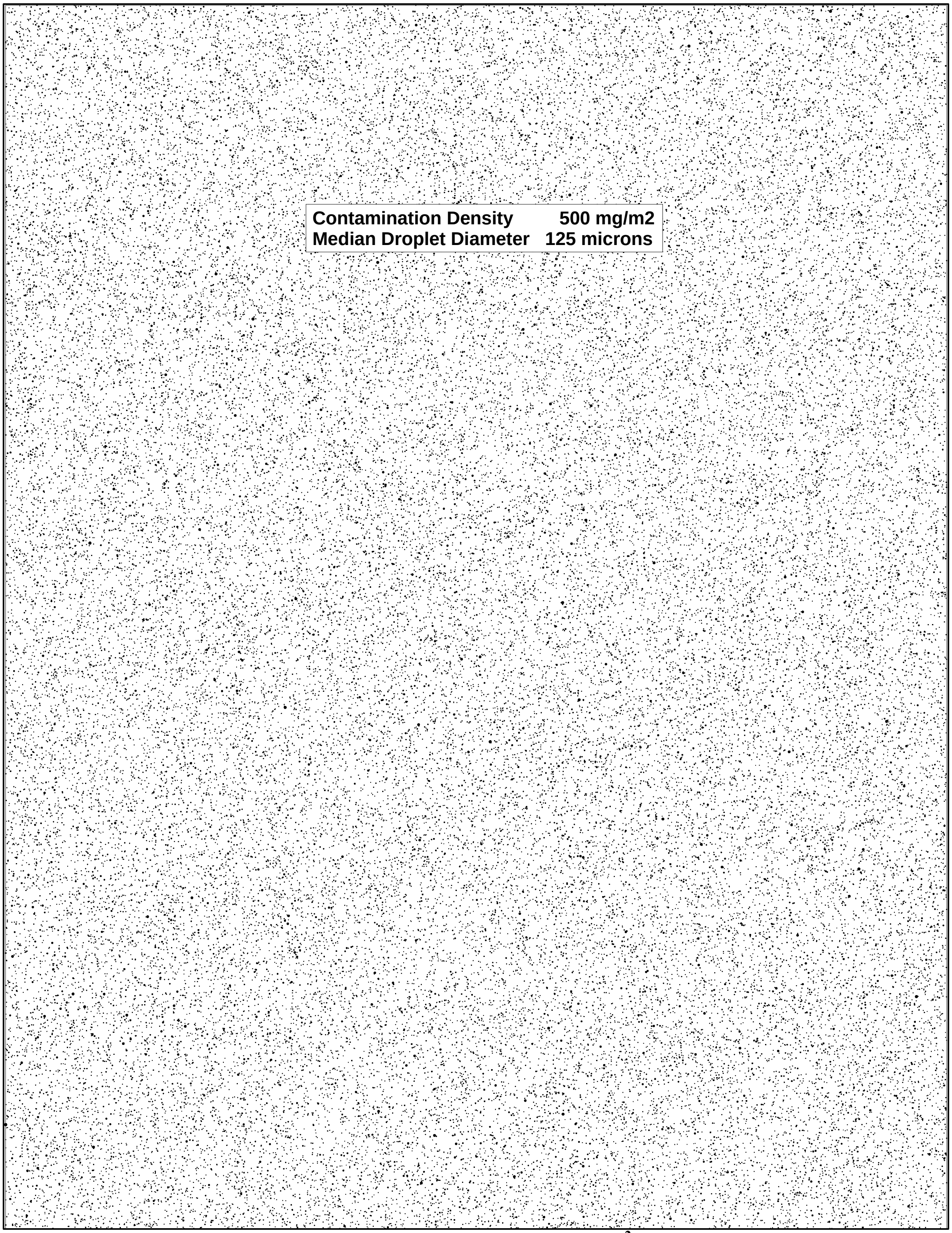


(U) Figure D6: M8 Paper with Contamination Density of 50 mg/m^2 and Median Droplet Diameter of 1000 Microns.

UNCLASSIFIED



(U) Figure D7: M8 Paper with Contamination Density of 500 mg/m^2 and Median Droplet Diameter of 125 Microns.

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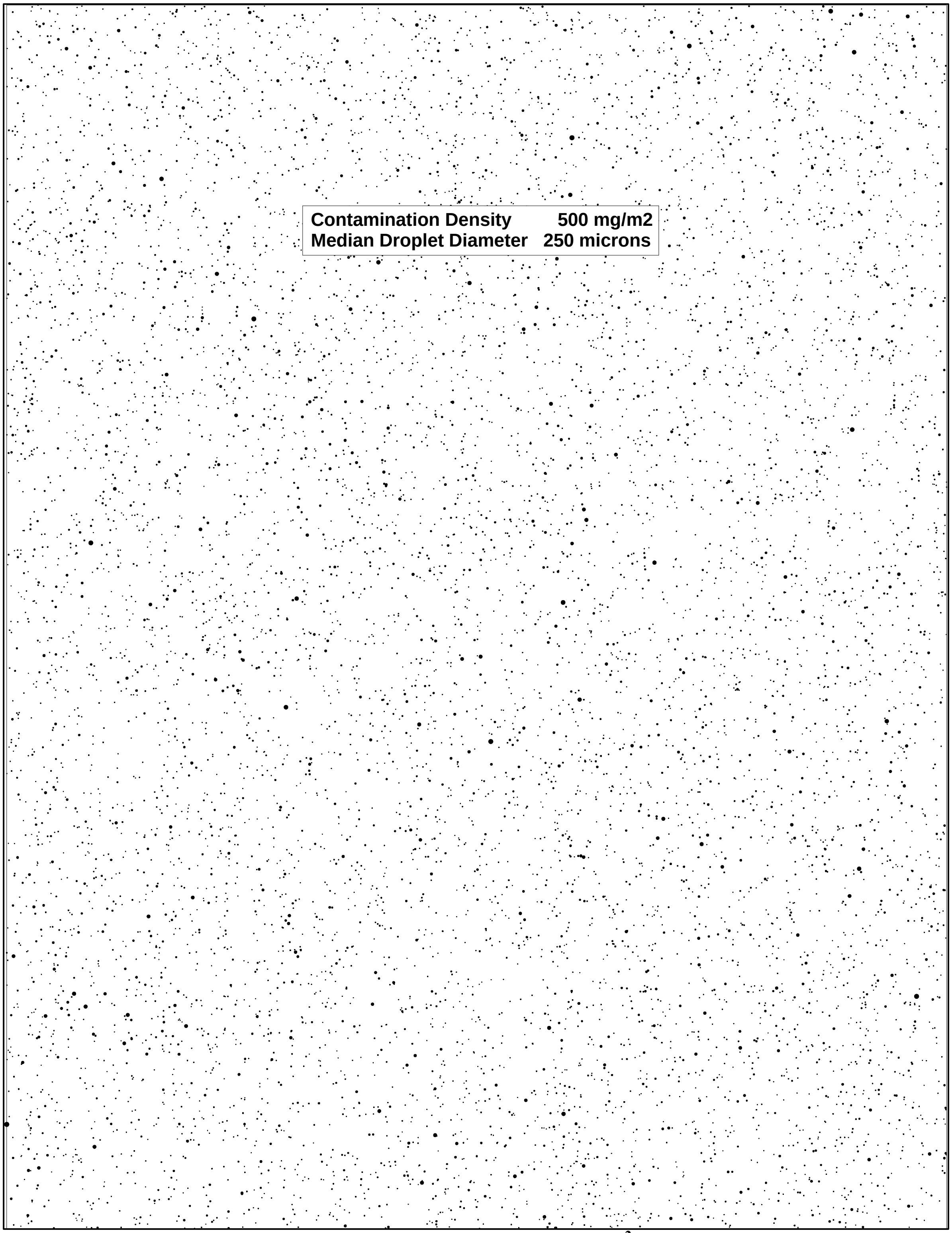

(U) Figure D8: M8 Paper with Contamination Density of 500 mg/m^2 and Median Droplet Diameter of 250 Microns.

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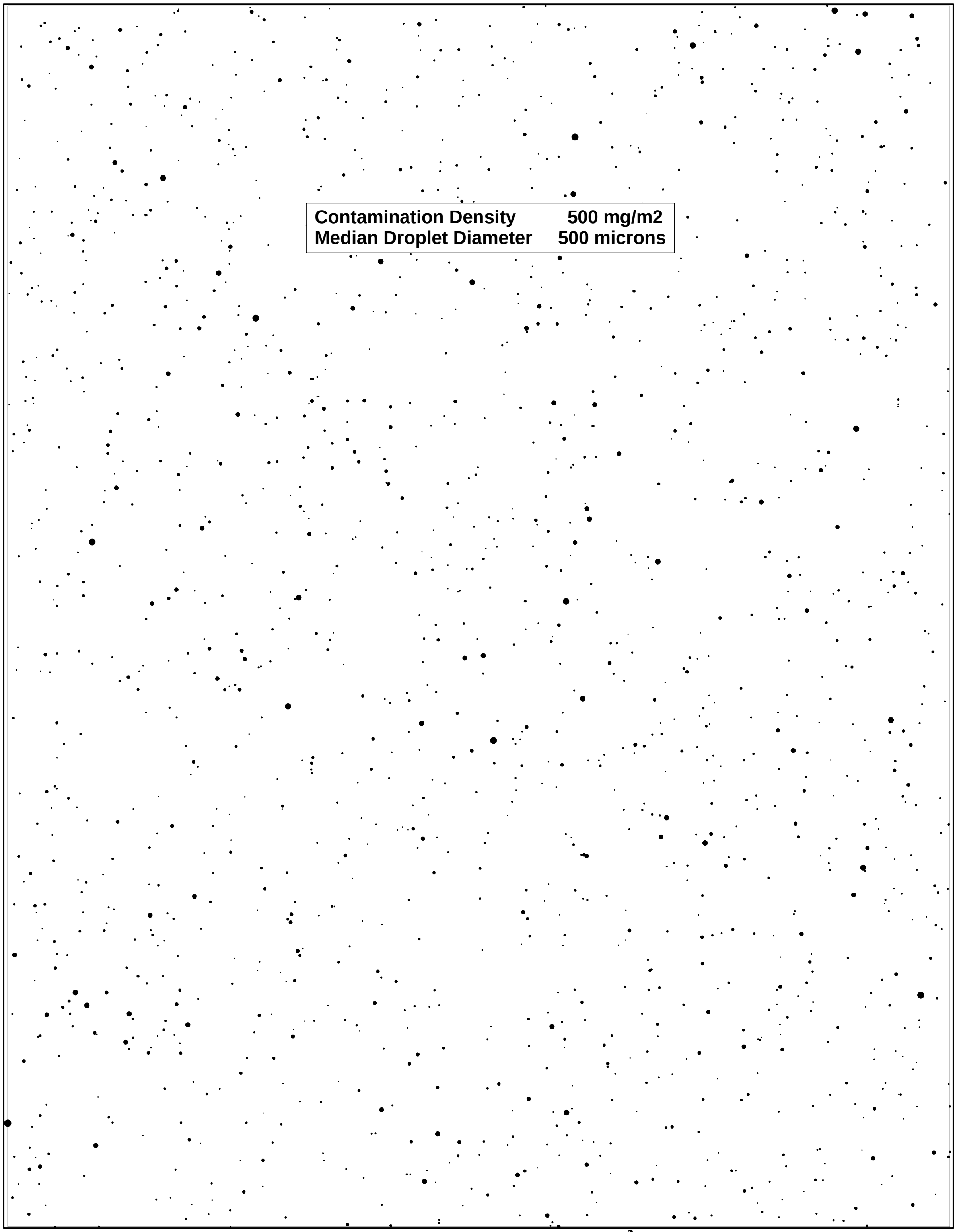

(U) Figure D9: M8 Paper with Contamination Density of 500 mg/m^2 and Median Droplet Diameter of 500 Microns.

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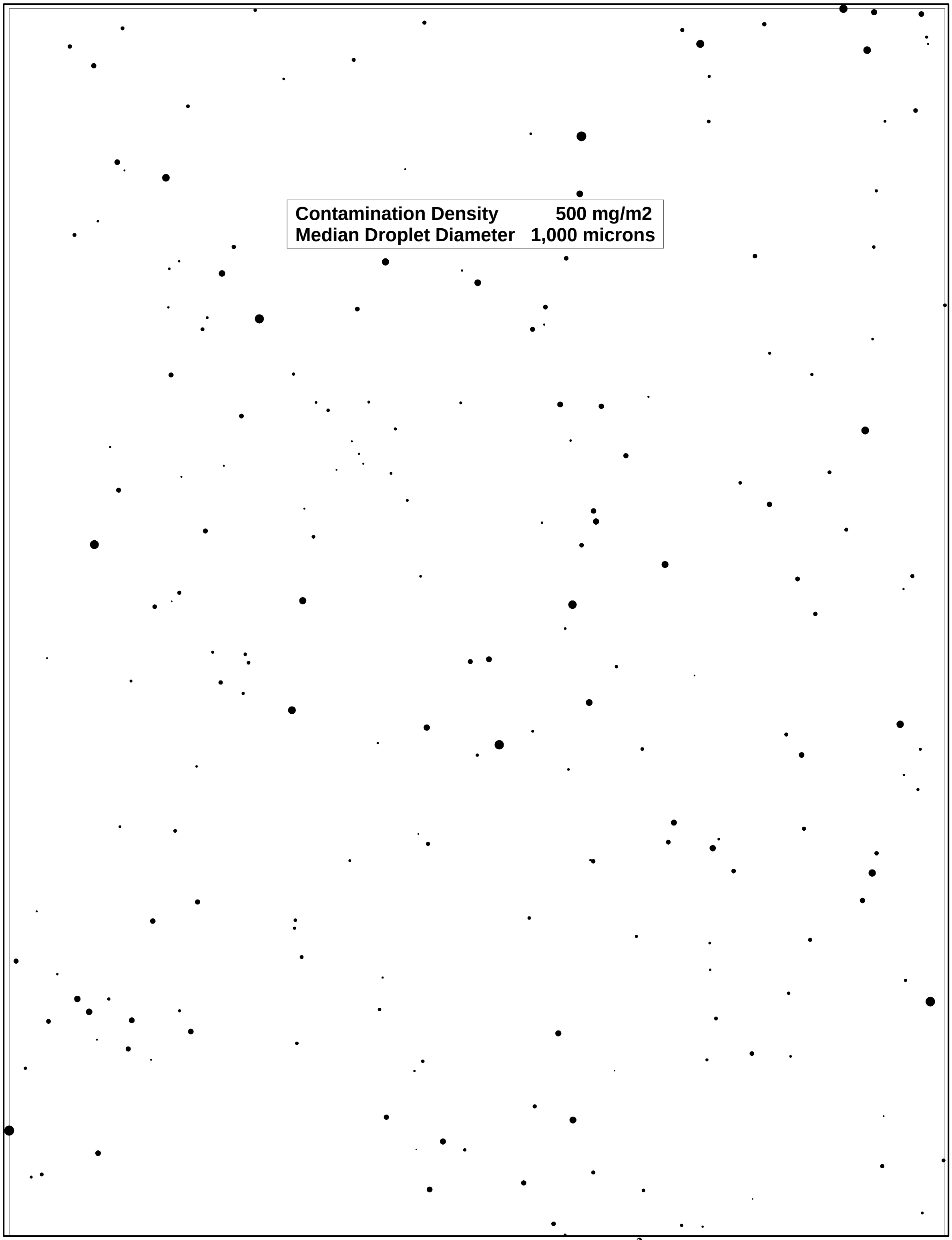

(U) Figure D10: M8 Paper with Contamination Density of 500 mg/m^2 and Median Droplet Diameter of 1000 Microns.

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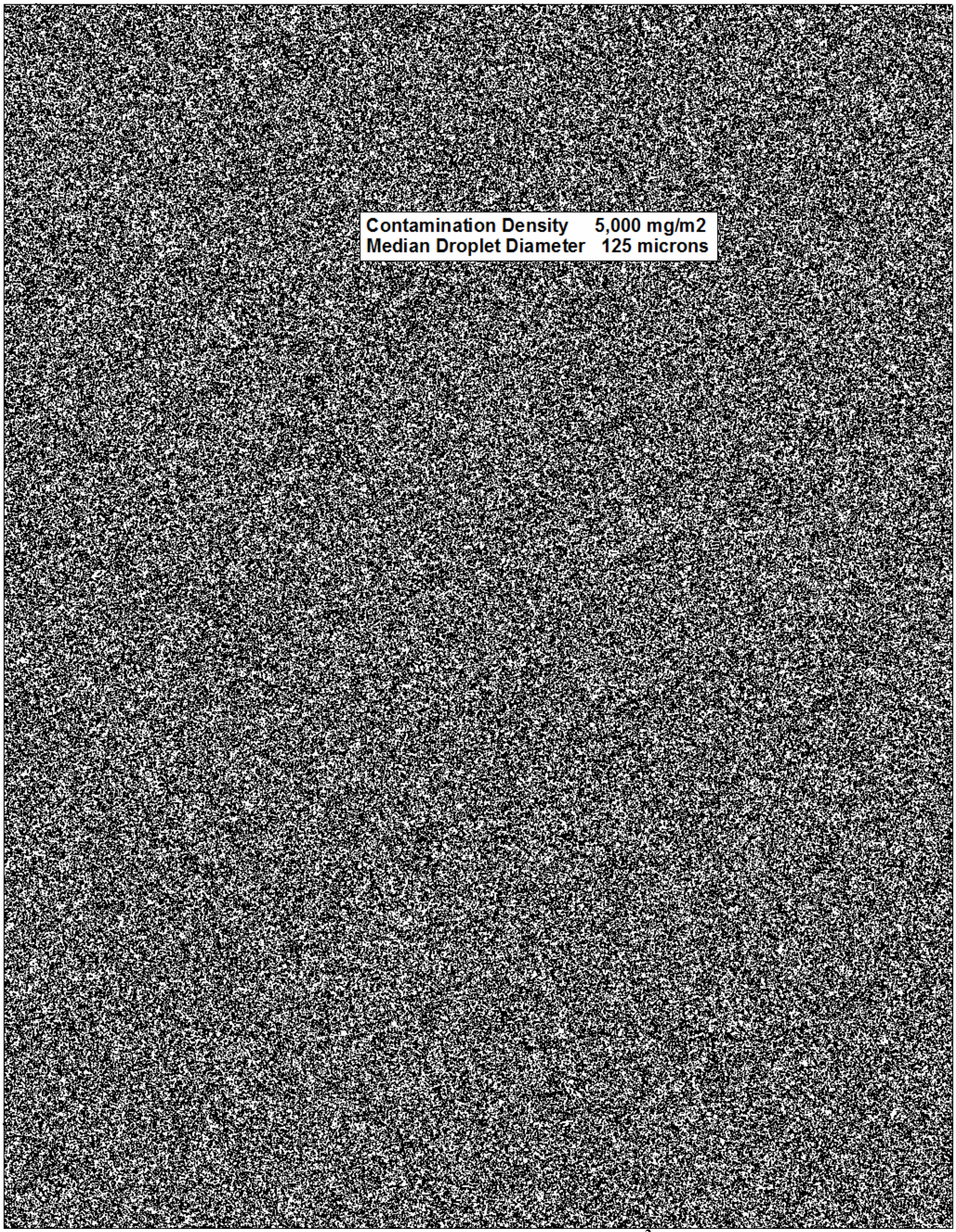
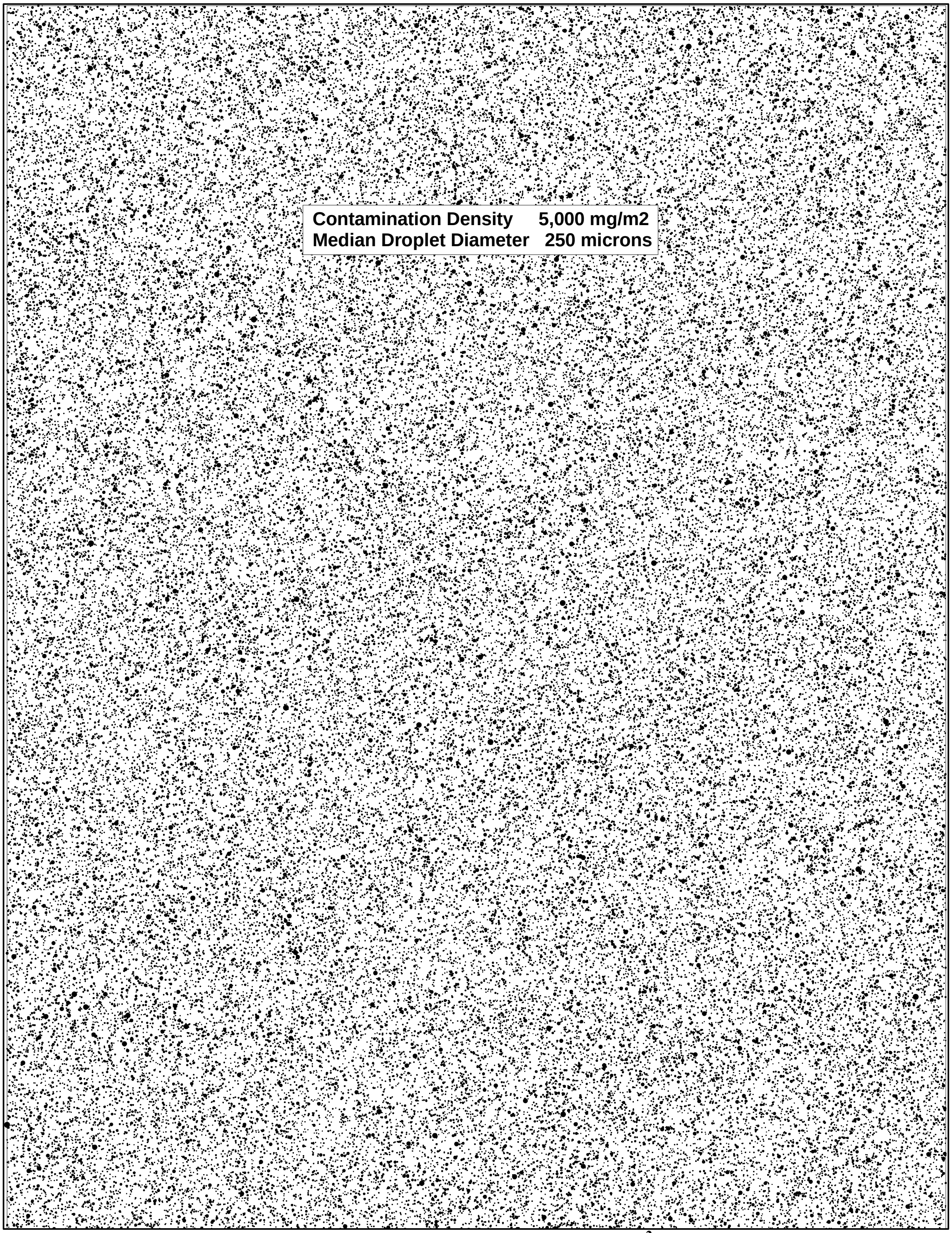


(U) Figure D11: M8 Paper with Contamination Density of 5000 mg/m^2 and Median Droplet Diameter of 125 Microns.

UNCLASSIFIED



(U) Figure D12: M8 Paper with Contamination Density of 5000 mg/m^2 and Median Droplet Diameter of 250 Microns.

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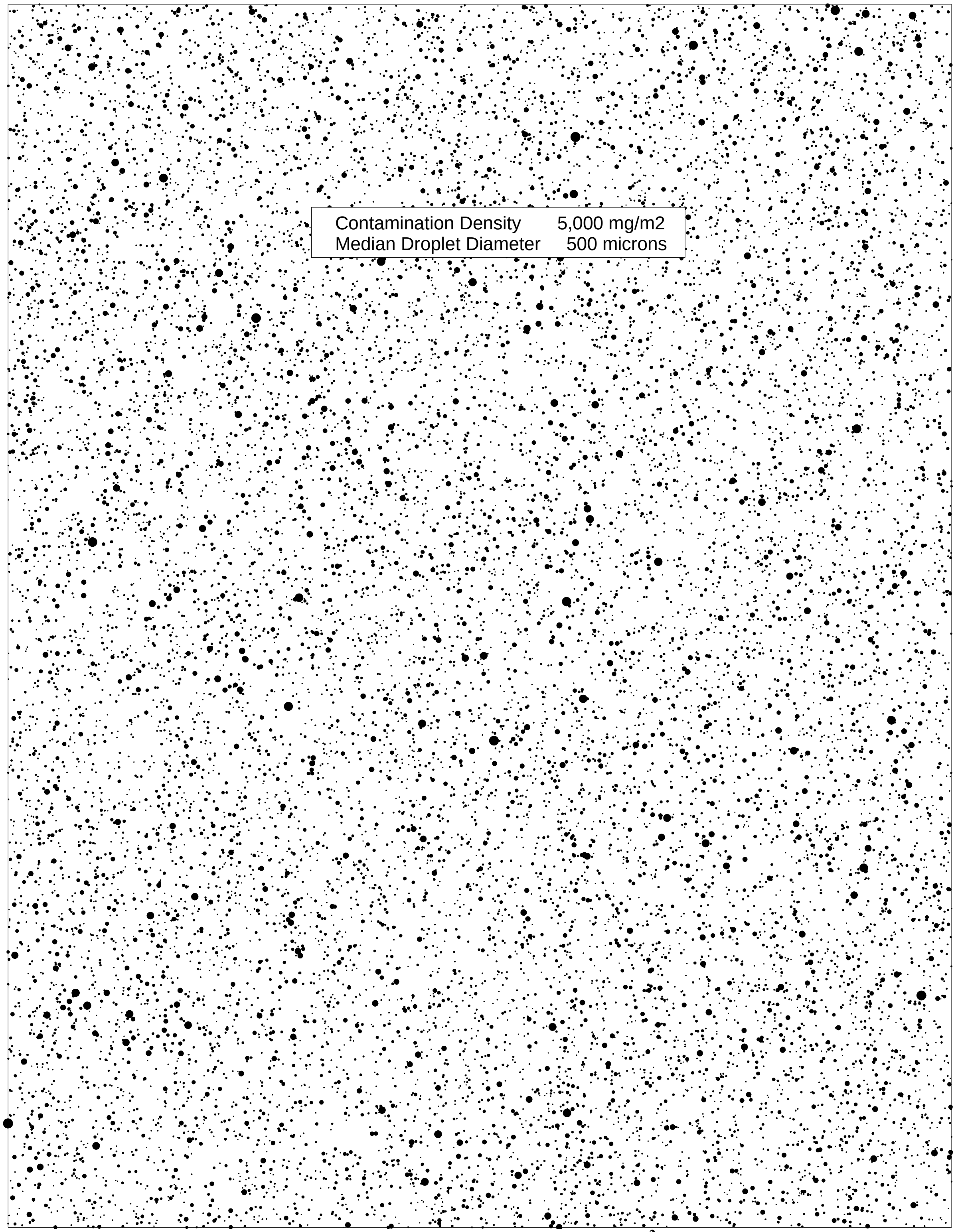

(U) Figure D13: M8 Paper with Contamination Density of 5000 mg/m^2 and Median Droplet Diameter of 500 Microns.

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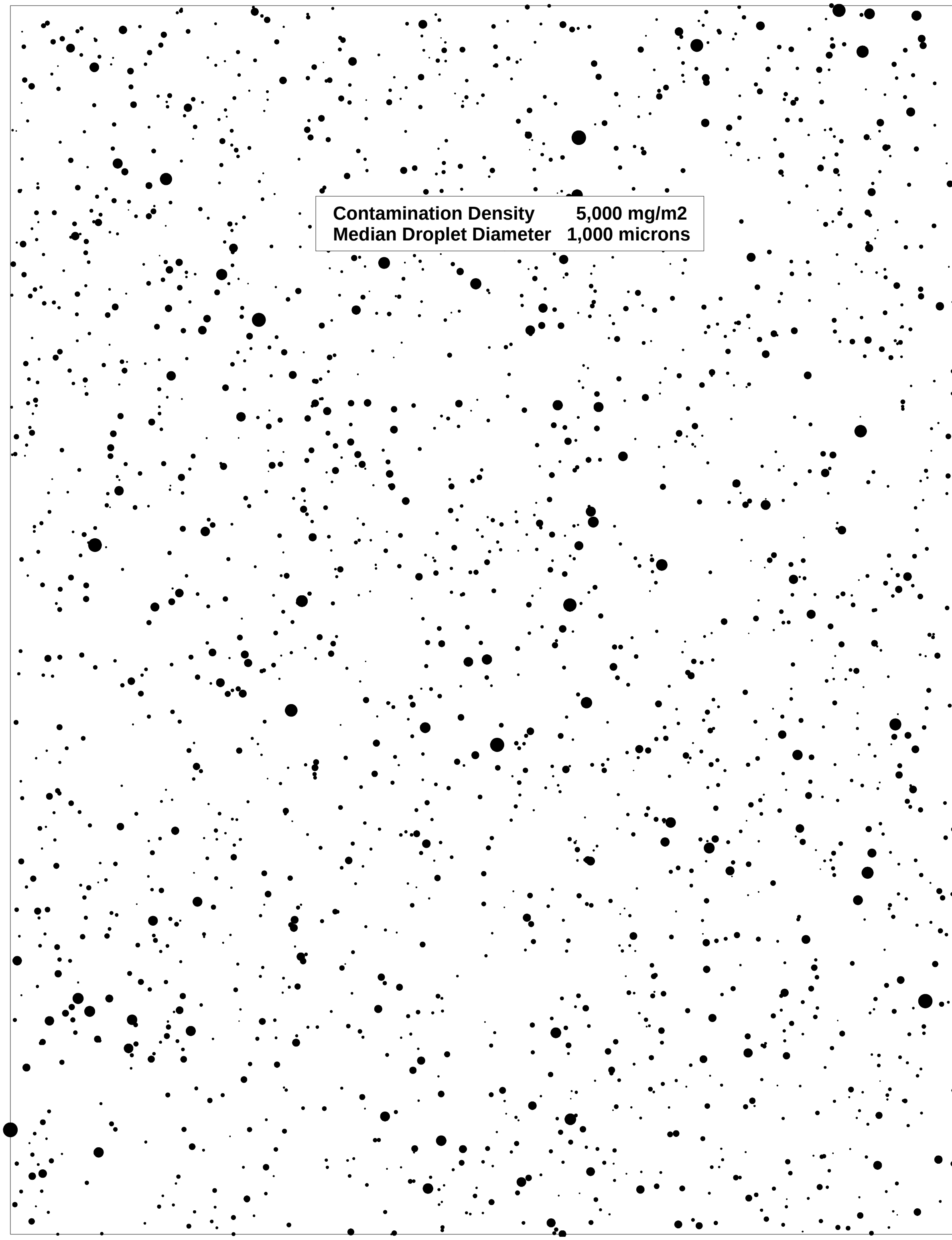
(U) Figure D14: M8 Paper with Contamination Density of 5000 mg/m^2 and Median Droplet Diameter of 1000 Microns.



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